UNCLASSIFIED

AD NUMBER
AD360876
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 2 May 1960. Other requests shall be referred to Defense Atomic Support Agency, Sandia Base, Albuquerque, NM.
AUTHORITY
DNA ltr, 5 Dec 1979; DNA ltr, 4 Dec 1979

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD 360876

CLASSIFICATION CHANGED
TO: UNCLASSIFIED
FROM: CONFIDENTIAL
AUTHORITY:
DNA notice
5 Dec 79

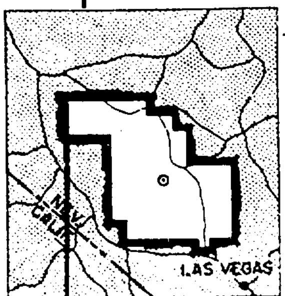
UNCLASSIFIED

[redacted]

WT-1441

This document consists of 50 pages.
No. 175 of 185 copies, Series A

OPERATION PLUMBBOB



NEVADA TEST SITE
MAY-OCTOBER 1957

Project 8.2

PREDICTION of THERMAL PROTECTION of UNIFORMS, and THERMAL EFFECTS on a STANDARD-REFERENCE MATERIAL (U)

Issuance Date: May 2, 1960

HEADQUARTERS FIELD COMMAND
DEFENSE ATOMIC SUPPORT AGENCY
SANDIA BASE, ALBUQUERQUE, NEW MEXICO

Inquiries relative to this repo[illegible] ay be made to

Chief, Defense Atomic Supp[illegible] Agency
Washington 25, D. [illegible]

When no longer required, this document may be destroyed in accordance with applicable security regulations.

DO NOT RETURN THIS DOCUMENT

[redacted]

WT-1441 [redacted]

OPERATION PLUMBBOB—PROJECT 8.2

PREDICTION of THERMAL PROTECTION of UNIFORMS, and THERMAL EFFECTS on a STANDARD-REFERENCE MATERIAL (U)

FOREIGN ANNOUNC... ...TION OF THIS REPORT BY DDC IS NOT AUTHORIZED.

W. L. Derksen
T. I. Monahan
J. Bracciaventi
J. A. Carter
A. Hirschman

Naval Material Laboratory
New York Naval Shipyard
Brooklyn 1, New York

U. S. GOVERNMENT ... REPORT DIRECTLY FROM DDC. OTHER ... THROUGH Sponsoring Agency to

Director
Defense Atomic Support Agency
Washington, D. C. 20301

This material contains information affecting the national defense of the United States within the meaning of the espionage laws Title 18, U. S. C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

[redacted]

FOREWORD

This report presents the final results of one of the 46 projects comprising the military-effect program of Operation Plumbbob, which included 24 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the military-effect program.

ABSTRACT

The purpose of Project 8.2, Operation Plumbbob, was to determine the adequacy of the laboratory methods employed in the study of the effects of intense thermal radiation on materials. The primary objectives were to determine the adequacy of physical methods for studying thermal damage to materials and for evaluating, by means of a physical skin simulant, the protection afforded by clothing to personnel against intense thermal radiation. A secondary objective of the project was to compare the burns predicted from the temperatures of the skin simulant behind an irradiated fabric assembly and the burns obtained on animals under identical exposure configurations. Project 8.2 made basic thermal radiation measurements for the use of Projects 4.1, 8.1, and 8.2.

The skin-simulant study involved a major participation at stations which received radiant exposures of 6.5 and 15.5 cal/cm^2 during the Shot Priscilla (36.6 kt) detonation and at a distance corresponding to a radiant exposure of 16.2 cal/cm^2 for the Shot Hood (74.1 kt) detonation. Project 8.2 also made supporting measurements during Shots Lassen and Wilson. Representative cellulosic materials were exposed during Shot Priscilla at stations corresponding to radiant exposures of 6.5, 8.5, 10, 13, 15 and 21 cal/cm^2 to determine whether the threshold ignition energies of these materials determined under field conditions verify the data predicted from laboratory studies. Basic thermal radiation measurements were made during Shots Lassen, Wilson, Priscilla, and Hood.

The results of this field experiment indicate good agreement between temperatures measured in the field and temperatures predicted by laboratory methods employed in thermal radiation studies. The exceptions were that the laboratory experiments would predict higher temperatures for 3.5 and the 7.5-cm-diameter areas for exposures for which cloth would be expected to ignite than those which were measured in the field experiment. Blast effects are postulated to account for this difference.

In three of the four situations for which postshot data were available, the skin simulant adequately predicted burns to pig skin exposed in similar exposure geometries.

Measurements of thermal radiation were made successfully, and showed reasonable agreement with the generalized pulse except for a slightly higher irradiance after the irradiance maximum for Shots Priscilla and Hood.

PREFACE

Corresponding to the primary objectives of Project 8.2, this report has been divided into two parts: (1) evaluation of laboratory methods for determining the protection afforded by uniform systems and the comparison of the skin burns predicted from the temperatures of the skin simulant with the burn severities obtained on pigs under similar exposure configurations, and (2) effects of thermal radiation on a standard reference material.

The basic thermal radiation measurements are covered in the Appendix of this report.

The authors wish to acknowledge the guidance and invaluable assistance of Major William C. Linton, USA, Director, Program 8, in surmounting the many difficulties which are associated with participation in field tests of this type.

The authors are indebted to George J. Dashefsky, Edward J. Jehle, and Joseph M. McGreevy of the Naval Material Laboratory for encouragement in the planning and execution of this project.

George Mixter, Jr., M.D., consultant to the Naval Material Laboratory on the Thermal Injury Project, assisted in the design of the burn-simulant response study, analyzed the burns of the animals, and gave invaluable support in the operational phases of this project.

Alfred Lawes is due major credit for the design, proper fabrication, and excellent records of the electrical circuitry associated with the oscillographic recording of the many transient temperatures. He skillfully designed and fabricated many specialized devices required for the successful achievement of the project objectives.

The following personnel of the Naval Material Laboratory assisted in the preparatory work at the laboratory: Joseph Filosa, Ralph C. Maggio, and Guy P. DeLhery.

Personnel of the Quartermaster Research and Development Command fabricated the special uniforms for the pigs employed in the animal skin-simulant study, in making pigs available for this purpose, and in coordinating the placement of the animals. Personnel of the U.S. Naval Radiological Defense Laboratory, particularly John M. Nichols, assisted in the developing of the oscillographic records.

The authors wish to gratefully adknowledge their indebtedness to Richard R. Deasy for his efficient job in typing the manuscript from rough notes under the duress of the field operation and for his many valuable suggestions.

CONTENTS

FIGURES

TABLES

Part I EVALUATION of LABORATORY METHODS for DETERMINING THERMAL PROTECTION of UNIFORMS

Chapter I
INTRODUCTION

1.1 OBJECTIVES

The objective of the skin-simulant study was to determine the adequacy of laboratory methods employed in studying the effects of intense thermal radiation on biological systems. More specifically, the purpose of this investigation was to: (1) determine the adequacy of the irradiation area, time variation of irradiance, and spectrum of the laboratory sources employed in evaluating the protection afforded to personnel by uniforms; and (2) compare the burn severity predicted from the temperature histories of a skin simulant behind an irradiated fabric assembly with the actual burns noted on animal skin irradiated under similar exposure configurations.

1.2 BACKGROUND AND THEORY

Thermal radiation damage to materials and personnel has been studied extensively at the Naval Material Laboratory (NML). Included have been both the critical radiant exposures required to cause typical damage to representative materials and the protection afforded to skin by various clothing assemblies. The purpose of Project 8.2 was to validate these laboratory study methods, the results of which are important to military and civil defense groups in evaluating operational and tactical situations.

1.2.1 Skin-Simulant Study. A skin simulant utilizing a temperature criterion for determining burn severity has been developed by NML for use as a substitute for animal and human skin in the study of subfabric radiant-energy burns (References 1, 2, and 3).

During Operation Upshot-Knothole (Reference 4), a full-scale experiment was conducted to evaluate the protection of uniform systems employing a polyethylene skin simulant. Since that time, refinements have been made in the skin simulant and in the techniques employed in evaluating the protection afforded by uniforms. The improved skin simulant has the thermal properties of an average human skin and closely resembles human skin in optical characteristics (Reference 3). This skin simulant includes a fine-wire thermocouple embedded at a depth of 0.05 cm, permitting the use of a maximum-temperature burn criterion with minor qualifications.

The experimental design for the field test included more replication than previous tests, a greater range of exposure areas was employed, and the radiant exposures were more representative of situations that would result in burns for the particular uniform assemblies employed. The situations were documented in the laboratory as to temperature histories, burns to rat skin, influence of area of exposure, relative humidity, and air flow.

The primary objective of the skin-simulant study in the field will have been achieved if the temperatures measured for the actual thermal radiation pulse from the nuclear device can be shown to be the same as the temperatures for exposures to the simulated device in the laboratory, either by direct comparison or by computation of both from heat-flow theory. The temperature histories for systems involving semi-infinite and finite media in contact with semi-infinite opaque and diathermous media have been derived for constant-irradiance pulses. The tempera-

ture histories for more complex radiant-energy pulses, such as those of nuclear weapons, may be computed by synthesizing the pulse with a series of constant-irradiance pulses. For the skin simulant, correspondence of the temperature maxima for the laboratory and field pulses should be an adequate criterion of validation, since the depth at which the thermocouple is placed in the simulant was chosen so that, on the basis of heat-flow theory, the maximum temperature rise of the medium would be the burn criterion (Reference 5).

1.2.2 Comparison of Skin-Simulant Response and Burns to Pigs. The improved NML skin simulant, molded from silica-powder-filled urea formaldehyde, has the thermocouple embedded at a depth of 0.05 cm in order to give burn predictions based on maximum temperature attainment. The basic criterion is a rise of 25 C or more for a second-degree burn to human skin or for a 2+ mild burn to pig skin. This criterion is based on the assumption of (1) the equivalence of a minimal white burn on the rat skin (or a 2+ mild burn in pig skin) to a second-degree burn in human skin, (2) an initial skin temperature of 31 C, and (3) correspondence of the thermal properties of pig, rat, and human skin. The accuracy of such a burn prediction in terms of indicent radiant exposure is estimated to be ± 10 percent. A skin-simulant temperature rise of 20 C or greater is estimated to correspond to a first-degree human burn or a 1+ moderate pig skin burn, and a rise of 35 C is estimated for a third-degree human burn or a 3+ mild pig burn. The latter estimations, probably accurate to ± 20 percent, are based on pig-burn data obtained at the University of Rochester (Reference 6). The best estimate as to the influence of initial skin temperature was used to correct the burn-severity criteria (Reference 7). Thus, for every degree centigrade over or under a pig skin temperature of 31 C, a correction of 0.9 C was applied to the 25 C criteria for 2+ mild burns.

Chapter 2
PROCEDURE

2.1 OPERATIONS

For its skin-simulant study, Project 8.2 participated in four shots: Lassen, Wilson, Priscilla, and Hood. For Shot Priscilla two major recording stations were instrumented at distances of 7,500 and 12,150 feet from ground zero. For Shot Hood, one station was instrumented at a distance of 10,500 feet from ground zero. In view of the requirement for NML to make basic thermal measurements during Shots Lassen and Wilson, minor stations were instrumented at a distance of 3,930 feet for both, providing actual experimental data for devices of relatively low yields.

The data obtained, the temperature histories of the simulant, were recorded on oscillographic equipment. The recording equipment at the major stations was installed in shelters below ground in order to minimize the effects of blast and prompt and residual gamma radiation. Protective covers were removed from exposure assemblies prior to the detonation. The various assemblies and recording equipment were recovered as soon after the detonation as practicable.

Project 8.1 coordinated the placement and the recovery of the pigs employed in the study of correlating the skin simulant response with macroscopic burn damage to pig skin.

2.2 INSTRUMENTATION

2.2.1 Skin-Simulant Study. The two major stations for Shot Priscilla were instrumented with twenty simulant units at each station. The thermocouples embedded in the skin simulants were connected to Heiland oscillographs, which recorded the thermal emf similar to those studied in the laboratory. To minimize the effects of popcorning (Reference 8), and of reflection of radiation from the desert floor (Reference 9), the assemblies were mounted at a height of 7 feet above the ground on panels secured to the station structures.

Six basically different uniform-simulant configurations were evaluated: the NML simulant, uncovered, with and without a layer of blackening; the Army's Hot-Wet uniform assembly (5-oz/yd^2 poplin, shade 116, over 4-oz/yd^2 white sheeting), both in form contact with the simulant and spaced 5 mm from the simulant; and a dark-gray, 9-oz/yd^2 cotton sateen over a 4-oz/yd^2 white sheeting, both in firm contact with the NML simulant and spaced 5 mm from the simulant.

The spectral absorptances of the simulant and the two outer fabrics were measured and are shown in Figure 2.1. The radiant absorptances were computed for the carbon-arc spectrum and are given in Table 2.1. From Figure 2.1 it may be seen that the skin simulant and the poplin are inversely selective to short wave length or visible radiation and longer infrared radiation. Therefore, significant differences in the spectra of the laboratory source and the field thermal pulse should result in appreciable differences in the temperature rise of the backing. If the carbon-arc laboratory source was deficient in visible radiation, the temperatures obtained in the laboratory under the poplin would be lower than those from the nuclear device and those for the uncovered simulant would be higher in the laboratory than in the field. Deficiencies in the infrared regions would cause inverse effects. The blackened simulant and the gray sateen were essentially neutral; consequently, differences in the spectra of the two sources should not have affected the temperature rise of the uncovered blackened skin simulant and that of the normal simulant behind the gray sateen.

The NML skin simulant was a 3.8-cm-diameter disk, 1.0 cm high, as shown in Figure 2.2. The skin simulant is also shown in Figure 2.2 in a 10-cm-diameter semicylindrical mount. Firm contact between cloth and skin simulant was achieved by means of springs, which held the fabric

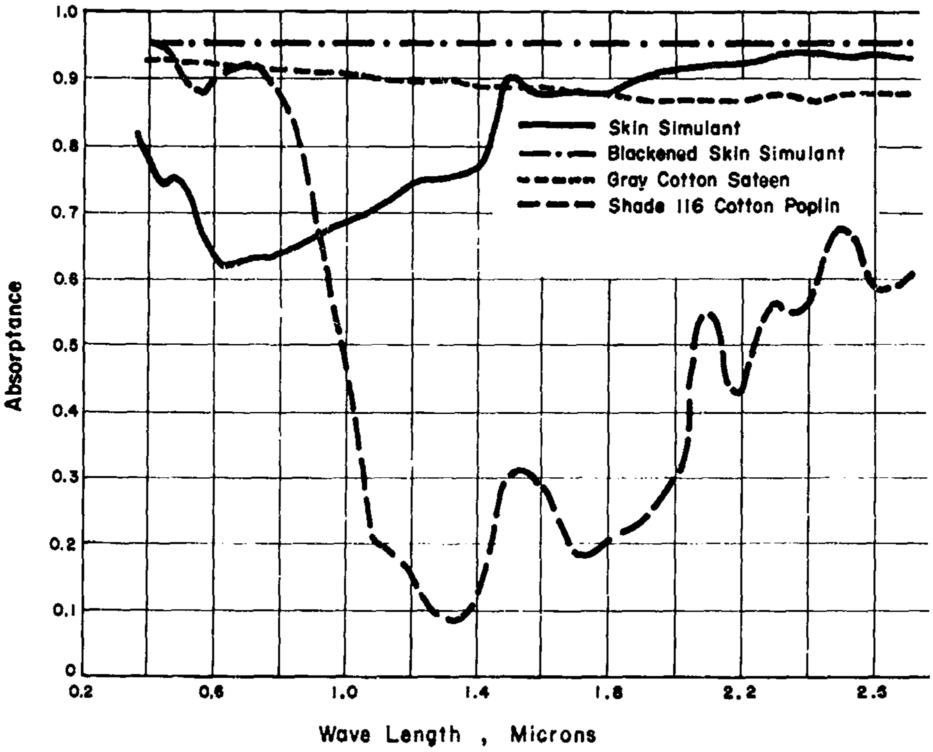


Figure 2.1 Spectral absorptances of NML skin simulant and standard fabrics.

Figure 2.2 Naval Material Laboratory skin simulant unmounted and mounted.

in tension against the curved surface of the simulant, as illustrated in Figure 2.3. For exposure areas larger than 3.5 cm in diameter, the skin simulant was mounted in a 10-cm-diameter polyethylene semicylinder 8 cm wide. Since polyethylene has thermal properties sufficiently like those of the skin simulant, cloth reactions under irradiation and the temperatures of the thermocouple in the simulant, for the exposure times and cloth thicknesses employed, should be the same as those for a backing entirely of the simulant material.

A lucite plate was employed to effect positive spacing for small-area and large-area exposures, as illustrated in Figure 2.4. The outer cloth was held with sufficient tension to pull the fabric apart when it lost its strength. Thin aluminum plates with holes of the appropriate diameter were fastened to the outer fabric to serve as apertures. These apertures were used to simulate sources having various irradiating areas. Several apertures are shown in Figure 2.5, which shows several specimens in place on a panel. Shields were employed to restrict the admission of thermal radiation to only the desired portions of the specimens.

Each of the six basic specimen configurations was repeated at least once, and some situations were repeated four times at each station for Shot Priscilla, employing apertures of 0.9, 1.7, 3.5,

TABLE 2.1 RADIANT ABSORPTANCES OF SKIN SIMULANT AND STANDARD FABRICS

Specimen	Radiant Absorptance
Skin simulant, bare	0.72
Skin simulant, blackened	0.95
Poplin, Shade 116, 5-oz/yd^2	0.63
Sateen, gray, 9-oz/yd^2	0.91

and 7.5 cm in diameter. The use of two stations for Shot Priscilla essentially duplicated the exposures at a second radiant-exposure level.

For Shot Hood the specimen configurations were similar to those for Shot Priscilla, except that all specimens were mounted at the one radiant-exposure level, attenuating screens being employed to obtain lower radiant exposures.

In Shots Lassen and Wilson, the following four exposure configurations were evaluated: (1) uncovered skin simulant, 3.5 cm aperture; (2) uncovered, blackened skin simulant, 3.5 cm aperture; (3) skin simulant in contact with Hot-Wet uniform, 1.7 cm aperture; (4) skin simulant in contact with dark-gray cotton sateen, white sheeting combination, 1.7 cm aperture.

At the designed radiant exposure of 15 cal/cm^2 the exposure configurations, in which the uniform assemblies were to be spaced from the skin simulant, should have involved ignition and required more precise control of the fabric's moisture content. These exposure assemblies at this station, therefore, were kept at a minimum moisture content by enclosure of the assemblies in a desiccated chamber. The window material was a thin film of plastic, polyvinylidene chloride (Saran), 0.0005 cm thick with an optical transmission factor of 0.90. The edges of the thin window were blackened in order that the initial phases of the thermal pulse would remove the window.

Motion-picture cameras operating at 64 frames/sec were employed at the two major recording stations during Shot Priscilla. The cameras were placed in front of the specimen racks to document the presence of smoke, flame, local dust or smoke obscuration, and other factors.

In the laboratory, the six configurations employed in the uniform evaluation study (see second paragraph of this section) were exposed to the carbon-arc thermal-radiation sources, whose irradiance duplicated the nuclear-device thermal pulses. A time to maximum, t_m, of 0.2 second, corresponding to a 40-kt device, was employed with radiant exposures ranging from 4 to 17 cal/cm^2 in terms of equivalent field radiant exposures, Q_f. Because the exposure was terminated at $9t_m$, the laboratory pulse delivered a radiant exposure of two times the product of the maxi-

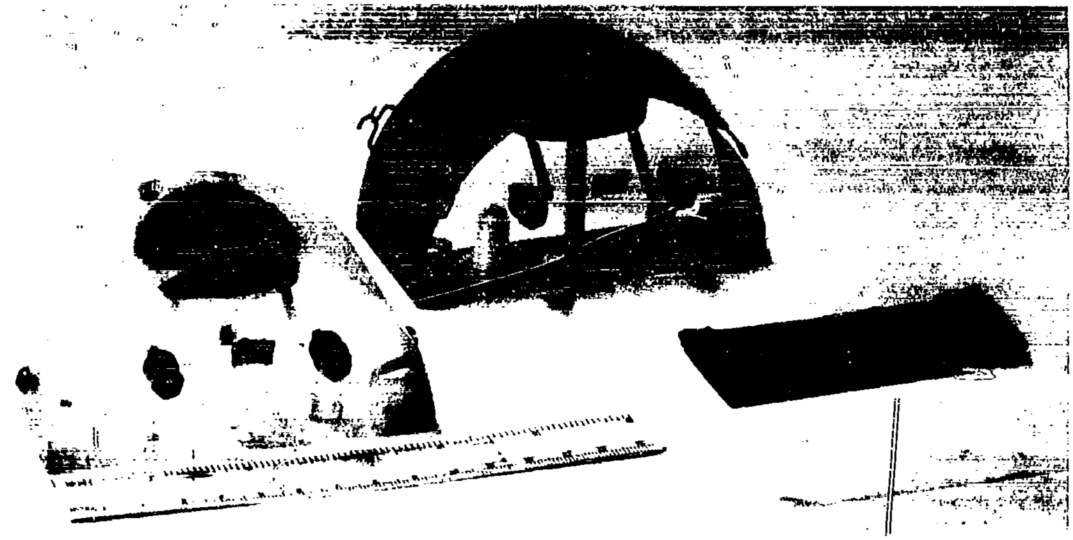


Figure 2.3 Method of mounting fabric assembly in contact with the NML skin simulant.

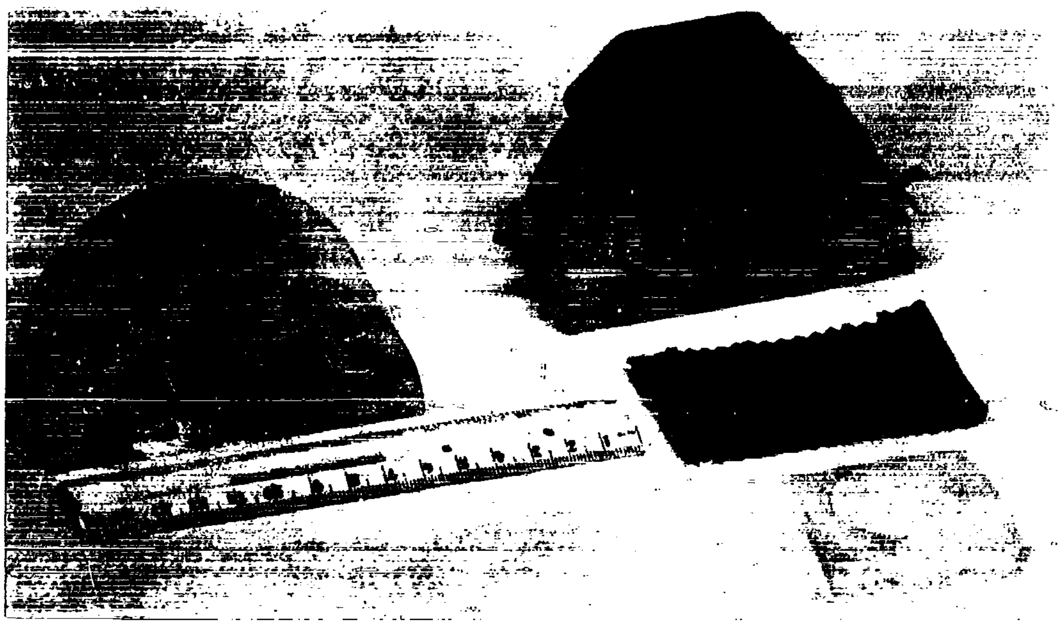


Figure 2.4 Method of mounting fabric assembly spaced away from the NML skin simulant.

mum irradiance, H_m, and t_m. The appropriate correction was applied to obtain Q_f, the equivalent field radiant exposure, which was given by:

$$Q_f = 2.57 \; H_m \; t_m$$

Exposures have been made to the carbon-arc sources without an aperture and with apertures of 0.9 and 1.7 cm in diameter to determine the influence of area of irradiation on the temperature

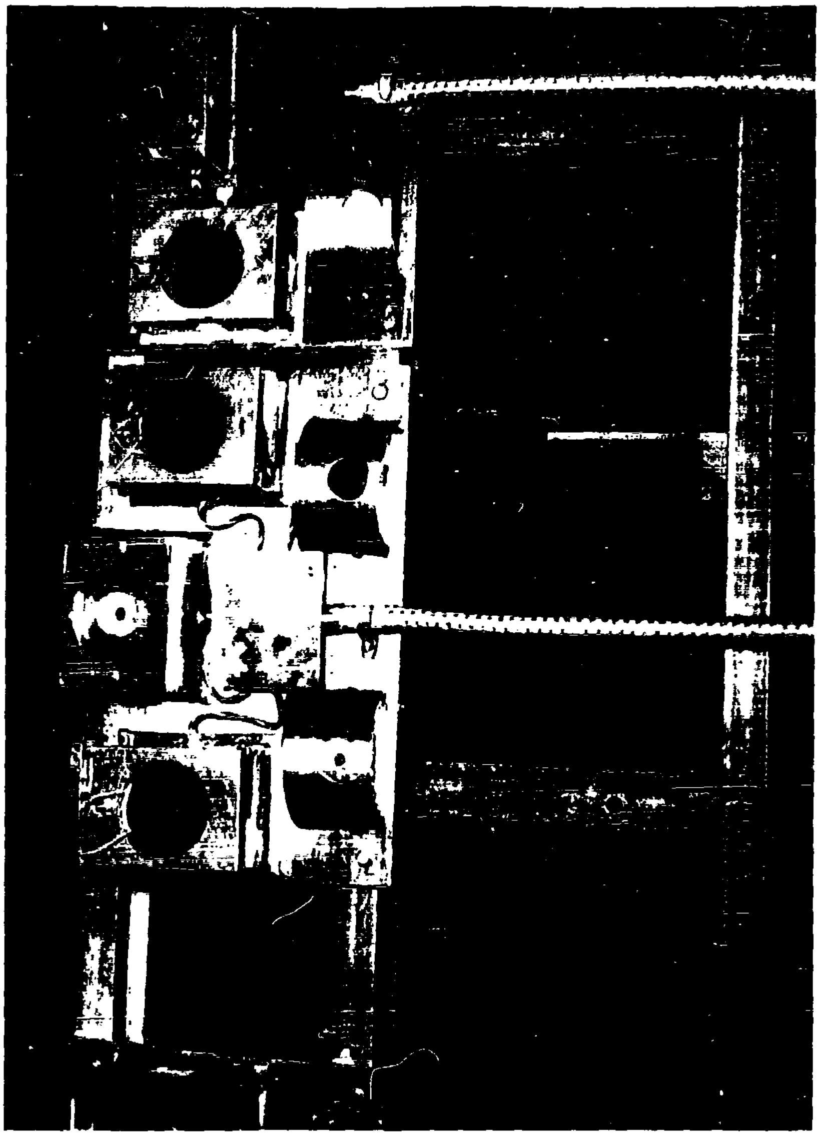


Figure 2.5 Typical skin-simulant exposure panel.
AFSWP Photo No. 30-65-PLK151-4.

rise of the skin simulant for the six different configurations. The distribution of irradiance in the exposure plane of the carbon-arc source is approximately Gaussian, the irradiance dropping to 90 percent of the irradiance maximum at a radial distance of approximately 0.8 cm.

To extend the study of exposure area to larger areas, a tungsten source employing a bank of tubular lamps was utilized. The area of irradiation was essentially uniform over an area 8 cm

in diameter. Since the irradiance was limited to a maximum of 6 cal/cm^2-sec and a variable shutter mechanism was not readily available, constant-irradiance exposures were employed.

2.2.2 Comparison of Skin-Simulant Response and Burns to Pigs. The fabric-animal exposure configurations duplicated three of those employed with the skin simulant. The 5-oz/yd^2 poplin was placed over the 4-oz/yd^2 bleached sheeting against the shaved pig; tension was applied to the cloth to provide firm thermal contact. The same cloth assembly was exposed with a 5-mm spacing between the cloth and the animal's skin. Apertures of 3.5 cm in 0.010-inch aluminum-faced cloth were employed. The spacing was obtained by placing a heavy fabric under the uniform assembly, with a hole cut to match the aperture over the uniform assembly. Portions of the sides of each pig exposed were left uncovered as control areas.

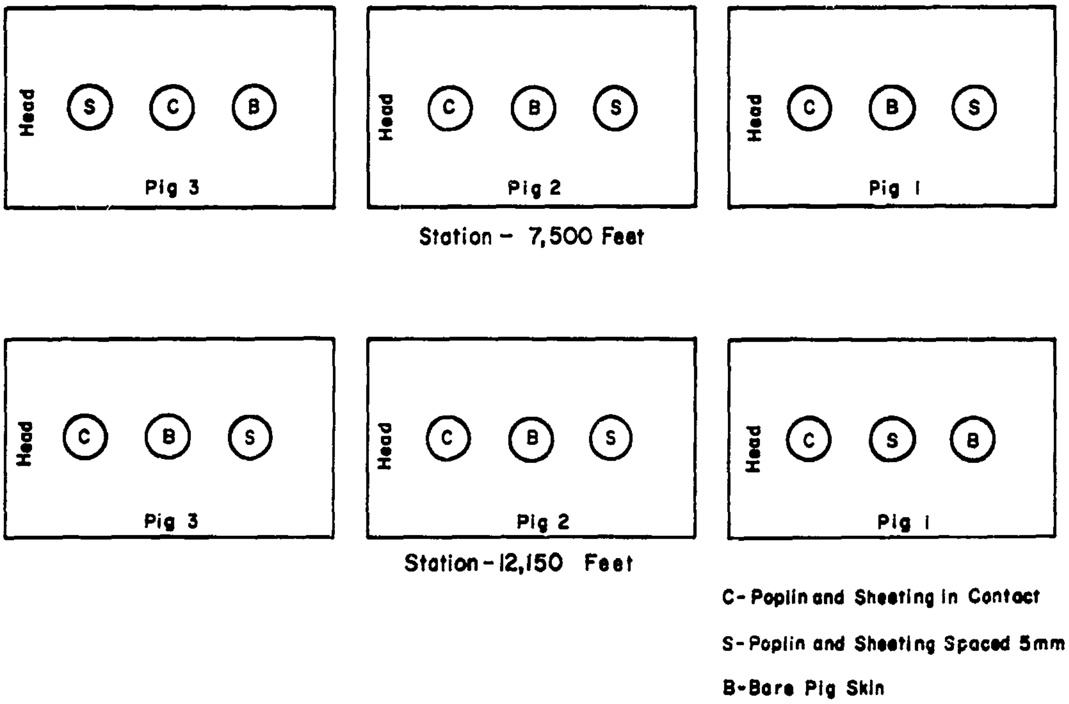


Figure 2.6 Schematic diagram of clothed pigs showing areas of controlled exposure.

A diagram showing the positions of the various fabric assemblies on a pig is presented in Figure 2.6.

After exposure during the detonation, the pigs were inspected at H + 2 and H + 24 hours to determine the nature and extent of the thermal injury under each of the exposed areas. The existence of burns, if present, was noted and the burns were graded as to severity. The data thus obtained were compared with the predictions from the response of the skin simulant.

2.3 DATA REQUIREMENTS

2.3.1 Skin-Simulant Study. The data required for the validation of laboratory methods of evaluating the protection afforded by uniforms were the maximum temperature rises produced in the skin simulants by the thermal radiation pulse of the nuclear detonation and the radiant exposures and irradiance history at the particular station.

The data were recorded in the form of 48 traces on four separate photographic oscillographic records. The skin-simulants' temperature histories were derived from the deflections of the

recorder traces by the use of the thermocouple constant (27 C/mv) and the sensitivity (mv/mm) as determined for the actual circuit employed at the respective stations. The maximum temperature rises thus obtained were compared directly with those predicted from laboratory exposures. Skin-simulant temperatures were measured in the laboratory for the range of radiant exposures expected in the field test, and the predicted values were adjusted for deviations from the anticipated radiant exposures. Any differences in the actual temperatures from the predicted values were studied to determine inadequacies in the laboratory evaluation methods. The influences of a sufficient number of parameters were evaluated in the field to permit drawing conclusions as to those aspects in which the laboratory exposures failed to duplicate the exposures to a nuclear detonation (whether the inadequacy may be attributed to differences in the spectra of the two sources, in their areas of irradiation, in their pulse shapes, etc.).

A record of temperature, relative humidity, pressure, and wind direction and velocity in the immediate region of the Project 8.2 stations was required. Such data permitted an evaluation of the validity of the field-test results. The presence or absence of dew on the windows of thermal-radiation meters and on materials, excessive air flow across the specimen, and other effects of the environment, if present, could account for significant differences between laboratory and field data. Therefore, the indicated meteorological data were required in order to evaluate these effects.

2.3.2 Comparison of Skin-Simulant Response and Burns to Pigs. The data required for comparing the temperature response of the skin simulant with the burn response of the pigs were the actual burn severities noted for each of the fabric-animal configurations at the two stations and the maximum temperature rise of the skin simulant for the corresponding fabric-simulant exposure condition. The same climatological data requested in the skin-simulant study were necessary in this study for proper evaluation of the results.

Chapter 3
RESULTS

3.1 LABORATORY DATA

Two experiments which were immediately applicable to the analysis of the field results were conducted in the laboratory. In one experiment, the various fabric-skin-simulant configurations were exposed to the carbon-arc source whose output simulated the thermal flux emitted by a nuclear detonation. The temperature rise of the skin simulant for each configuration is given in Figure 3.1 as a function of the equivalent field radiant exposure for a 40 kt device. The temperature rise of the skin simulant for these configurations is given in Figure 3.2 as a function of simulated-device yield.

The temperature rise of the skin simulant for the various configurations when exposed to the side-area tungsten source is given in Table 3.1 as a function of the area of exposure. The exposure durations were selected to give a maximum temperature rise equal to that obtained for a radiant exposure of 5 cal/cm^2 for a pulse with a simulated yield of 40 kt. Because of spectral differences between sources, the exposures were longer for the poplin than for the gray sateen. To simulate exposures at the 15-cal/cm^2 station, the exposures were made three times as long as those for 5 cal/cm^2. At the lower radiant exposure, it will be noted that for the fabrics in contact the differences between the 0.9-cm and the 7.5-cm exposures are more than 10 percent; for the spaced configuration the differences are large; however, the temperature rises are low, and these differences have no practical significance. For the exposures equivalent to a field radiant exposure of 15 cal/cm^2, high temperatures were experienced for all areas of contact; however, for the spaced situation the amount of cloth burned in the smaller aperture was usually insufficient to cause temperatures normally associated with flaming cloth of appreciable size. Temperature maxima when the cloth was ignited and either glowed or flamed varied between rather wide limits but were usually greater than those associated with the 2+ burn level.

3.2 SHOT LASSEN

Because of the device's extremely low yield, the temperature rises of the skin simulant for all exposure configurations evaluated were negligible during Shot Lassen.

3.3 SHOT WILSON

The temperature-rise maxima measured are given in Table 3.2 for the four specimens exposed to Shot Wilson. The radiant exposure as measured at the station was 17.5 cal/cm^2 with a t_m of 0.11 second. The laboratory values were extrapolated from exposures longer than 0.2 second t_m. The temperature of the uncovered simulant was 17 percent less than predicted, and the blackened skin simulant was 31 percent less. Temperature rises in excess of 60 C are seldom employed in laboratory work, since they are much in excess of the burn levels of interest. The face of the blackened simulant was charred. Temperatures as high as 120 C have been exceeded in the laboratory for longer pulses without charring to the extent noted. The field exposure to the short pulse with a t_m of 0.1 second of 17.5 cal/cm^2 evidently produced the steep temperature gradient predicted by heat-flow theory for opaque substances. The clothed-simulant temperatures were high and characteristic of a flaming or glowing outer cloth, an effect which was to be expected at this radiant exposure.

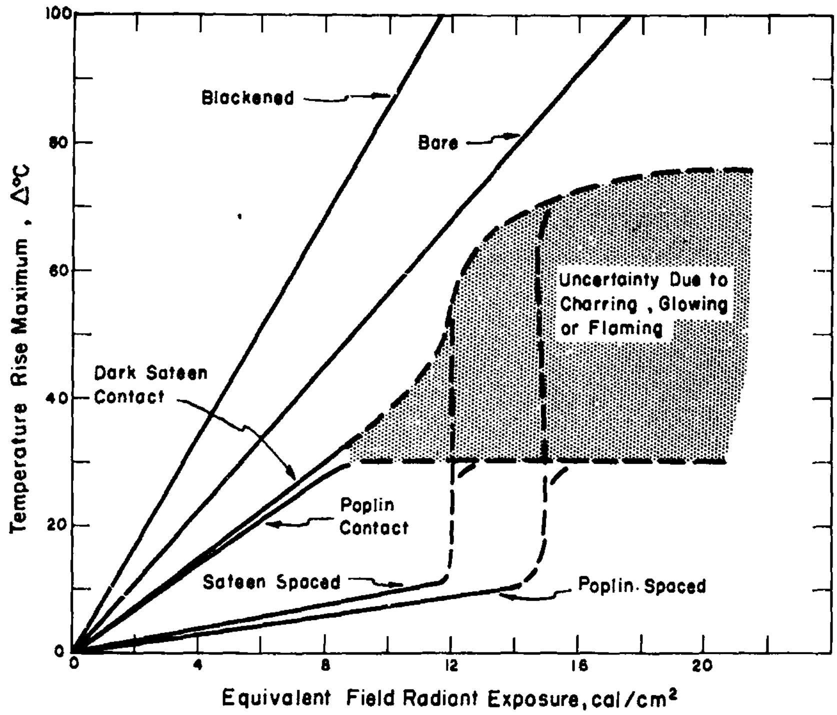


Figure 3.1 Maximum temperature rise of NML skin simulant predicted by laboratory exposures for a 0.2 second t_m pulse.

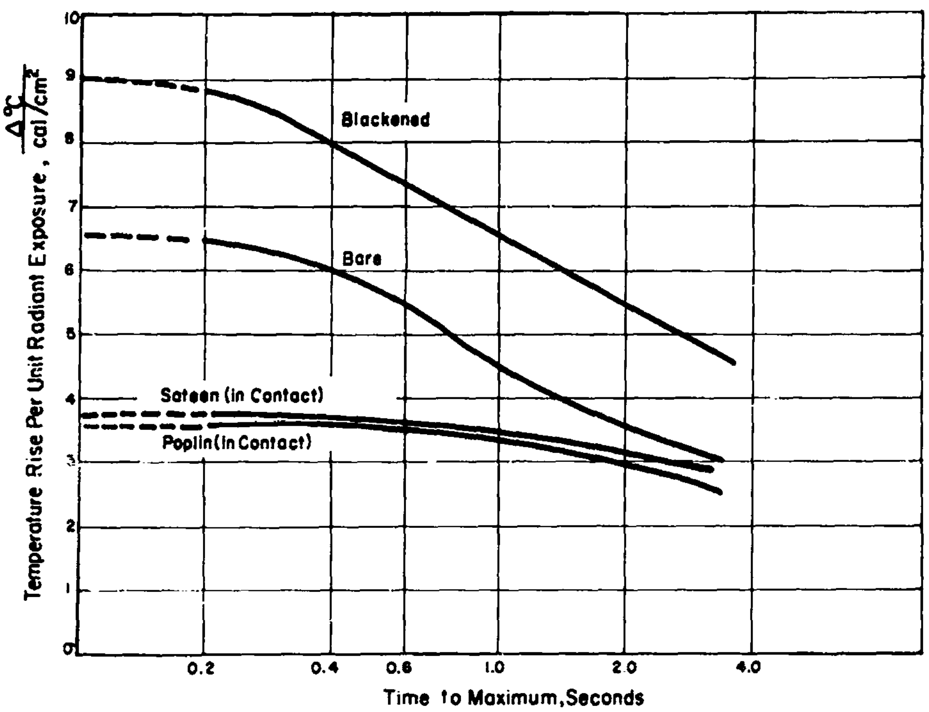


Figure 3.2 Maximum temperature rise of NML skin simulant versus pulse length.

3.4 SHOT PRISCILLA

3.4.1 Skin-Simulant Study. The maximum skin-simulant temperatures are given in Table 3.3 for the 7,500-foot station and in Table 3.4 for the 12,150-foot station for Shot Priscilla. One oscillograph failed to run and the data are incomplete for this reason. The laboratory values have been derived for radiant exposures of 6.5 and 15.0 cal/cm^2 and from the data of Figures

TABLE 3.1 TEMPERATURE RISE OF CLOTHED SKIN SIMULANTS AS A FUNCTION OF AREA OF EXPOSURE FOR A 3,000 DEGREE KELVIN TUNGSTEN SOURCE

Specimen, Skin Simulant Covering	t_{sw}*	Radiant Exposure		Temperature Rise for Aperture Diameter			
		Square Wave	Field Equivalent	0.9 cm	1.7 cm	3.5 cm	7.5 cm
	sec	cal/cm^2	cal/cm^2	C	C	C	C
Poplin and sheeting in	0.91	5.5	5	16	18	19	19
contact	2.7	16.5	15	30 to 60	30 to 60	30 to 60	30 to 60
Gray sateen and sheeting	0.70	4.3	5	17	19	19	22
in contact	2.1	12.8	15	30 to 60	30 to 60	30 to 60	30 to 60
Poplin and sheeting	0.91	5.5	5	2	3	5	5
spaced 5 mm	2.7	16.5	15	10	12	30 to 60	30 to 60
Gray sateen and sheeting	0.7	4.3	5	2	3	5	5
spaced 5 mm	2.1	12.8	15	20	28	30 to 60	30 to 60

* t_{sw}, duration of square wave pulse.

3.1, 3.2, and Table 3.1. For the specimens which were expected to flame, a range of temperature rises is indicated, the predicted temperatures being in excess of those corresponding to the important burn level for the larger apertures.

The influence of blast, such as causing the removal of a burning or glowing cloth, is to be discounted as reflecting on the adequacy of laboratory methods in this investigation. During

TABLE 3.2 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT 3,930-FOOT STATION, SHOT WILSON

Laboratory values are for 17.5 cal/cm^2 and a t_m of 0.11 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	3.5	114	95	−17
2	Uncovered, blackened	3.5	168	116	−31
3	Poplin and sheeting in contact	1.7	30 to 60	51	—
4	Gray sateen and sheeting in contact	1.7	30 to 60	38	—

Operation Upshot-Knothole, blast in most cases only served to reduce the temperatures which had already exceeded the temperatures associated with burns by blast time.

The temperatures of the simulants in firm contact with the cloths at the 7,500-foot station were as high or higher than those predicted for the flaming cloth. Behind the ignited spaced

TABLE 3.3 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANTS AT 7,500-FOOT STATION, SHOT PRISCILLA

Laboratory values are for 15.0 cal/cm² and a t_m of 0.20 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	100	93	−7
2		3.5	100	94	−6
3	Blackening	3.5	140	115	−18
4	Poplin and	0.9	30 to 60	53	—
5	sheeting in contact	7.5	30 to 60	71	—
6	Gray sateen	0.9	30 to 60	77	—
7	and sheeting	0.9	30 to 60	46	—
8	in contact	7.5	30 to 60	47	—
9	Poplin and	0.9	10 *	16	—
10	sheeting	1.7	12	19	—
11	spaced 5 mm	3.5	30 to 60	25	—
12		7.5	30 to 60	30	—
13	Gray sateen	0.9	20 *	14	—
14	and sheeting	1.7	28	20	—
15	spaced 5 mm	3.5	30 to 60	22	—
16		7.5	30 to 60	22	—

* Lab temperature rise maxima are critically dependent on completion of combustion. Differences in ignition and not maximum temperature rise are significant in these situations.

TABLE 3.4 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANTS AT 12,150-FOOT STATION, SHOT PRISCILLA

Laboratory values are for 6.5 cal/cm² and a t_m of 0.20 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	42	*	—
2		3.5	42	*	—
3	Blackening	0.9	59	50	−15
4		3.5	59	*	—
5	Poplin and	0.9	21	*	—
6	sheeting	1.7	24	26	+8
7	in contact	3.5	24	25	+4
8		7.5	24	*	—
9	Gray sateen	0.9	22	25	+14
10	and sheeting	1.7	24	26	+8
11	in contact	3.5	24	24	0
12		7.5	24	*	—
13	Poplin and	0.9	2	*	—
14	sheeting spaced 5 mm	7.5	4	*	—
15	Sateen and	0.9	2	*	—
	sheeting spaced 5 mm	7.5	5	*	—

* Temperatures were not recorded.

cloths, the temperatures, while indicating skin burns, were not as high as those predicted from laboratory exposures. The temperature histories peaked at 5 to 7 seconds and indicated that the blast blew out the flame. When flaming is not interfered with, the high erratic temperatures are maintained as long as 30 seconds. The temperatures predicted by laboratory methods for Shot Priscilla were too high by about 10 percent for the bare-and-blackened simulant and too low by 7 percent for the cloth-covered simulants.

The air temperature during Shot Priscilla was 17.5 C and the relative humidity 29 percent; the air was calm. The correlation of the effects of thermal radiation to those obtained under normal laboratory conditions would not have been affected by this environment.

3.4.2 Comparison of Skin-Simulant Response and Burns to Pigs. Table 3.5 lists the burns predicted from the temperatures measured in the skin simulants and the burns observed on the

TABLE 3.5 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AND RESPONSE OF PIGS AT THE 7,500-FOOT AND 12,150-FOOT STATIONS, SHOT PRISCILLA

Specimen		Radiant	Burn	Skin Simulant		Initial
Pig Covering	Pig No.	Exposure	Assessment	Temperature Rise Maximum	Predicted Burn Severity	Skin Temperature
		cal/cm²		C		C
Bare	1	6.5	1+ mild	—	—	—
	2		1+ mild			36
	3		No burn			31
	1	15	3+	93	In excess	—
	2		2+		of 3+	—
	3		3+			—
Poplin and	1	6.5	1+ severe	25	2+ mild	—
sheeting	2		No burn		2+ mild	38
in contact	3		1+ mild			36
	1	15	3+	60	In excess	—
	2		1+ mild		of 3+	—
	3		2+			—
Poplin and	1	6.5	1+ mild	—	—	—
sheeting	2		No burn			—
spaced 5 mm	3		1+ mild to no burn			—
						—
	1	15	3+	27	In excess	—
	2		No burn		of 2+	—
	3		No burn			

three pigs at the 7,500-foot station and the three pigs at the 12,150-foot station. The results of the measurements of initial skin temperature are also listed for the two animals it was possible to instrument. Unfortunately, the field data for the uncovered simulant and for the spaced uniform were not obtained at the lower radiant exposure when the one oscillograph did not function. Laboratory measurements have indicated that the temperature rise of 42 C expected for the uncovered simulant would have caused a prediction of a burn much more severe than was actually observed. For the poplin and sheeting spaced, a low simulant temperature would be indicated from laboratory measurements, and a no-burn observation would have been predicted.

While every effort was made to shave the pig skin thoroughly, and almost no stubble remained, the cloth-to-skin attitude was not ideal. The pig-burn results for 15 cal/cm^2 and for cloth contact probably reflect inadequate control of contact. The thermal contact was probably less than that possible with the curved simulant, which had a smooth, hard surface and provision for positive cloth tension.

The skin-simulant temperatures on Shot Priscilla afforded adequate predictions of the pig skin burns in three of the four situations where a comparison was possible and would certainly

TABLE 3.6 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT 10,500-FOOT STATION, SHOT HOOD

Laboratory values are for 16.3 cal/cm² and a t_m of 0.27 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	105	81	−23
2		3.5	105	75	−29
3	Blackening	0.9	142	113	−20
4		3.5	142	114	−20
5	Poplin and	0.9	30 to 60	47	—
6	sheeting	7.5	30 to 60	71	—
	in contact				
7	Gray sateen	0.9	30 to 60	46	—
8	and sheeting	7.5	30 to 60	53	—
	in contact				
9	Poplin and	0.9	10 *	5	—
10	sheeting	1.7	12	19	—
11	spaced 5 mm	1.7	12	17	—
12		1.7	12	25	—
13		3.5	30 to 60	27	—
14		7.5	30 to 60	34	—
15	Gray sateen	0.9	20 *	14	—
16	and sheeting	1.7	28	20	—
17	spaced 5 mm	1.7	28	22	—
18		3.5	30 to 60	30	—
19		7.5	30 to 60	33	—

* Lab temperature rises are critically dependent on amount of cloth actually burned. Differences in ignition are important here rather than temperature rises.

TABLE 3.7 MAXIMUM TEMPERATURE RISE OF SKIN SIMULANT AT THE 10,500-FOOT STATION, SCREENED EXPOSURES, SHOT HOOD

Laboratory values are for 4.0 cal/cm² and a t_m of 0.27 second.

Specimen	Specimen, Skin Simulant Covering	Aperture Diameter	Maximum Temperature Rise		Difference
			Laboratory	Field	
		cm	C	C	percent
1	Uncovered	0.9	26.3	25.2	−4
2		3.5	26.3	25.8	−2
3	Blackening	0.9	35.3	40	−13
4		3.5	35.3	40	−13
5	Poplin and	0.9	14	16	+14
6	sheeting	1.7	15	21	+40
7	in contact	1.7	15	17	+13
8		1.7	15	21	+40
9		3.5	15	22	+46
10		7.5	15	23	+53
11	Gray sateen	0.9	14	19	+36
12	and sheeting	1.7	15.5	21	+39
13	in contact	1.7	15.5	22	+42
14		3.5	15.5	20	+32
15		7.5	15.5	24	+55
16	Poplin and	0.9	2	3	—
17	sheeting	7.5	4	4	—
	spaced 5 mm				
18	Gray sateen	0.9	2	1.5	—
19	and sheeting	7.5	5	5	—
	spaced 5 mm				

have permitted prediction of the no-burn observation under the spaced assembly at the 12,150-foot station. Simulant temperature did not predict the no-burn observation under assembly in contact at the 12,150-foot station. The possible lack of positive contact of cloth to pig skin and the contribution of the postulated correction to the burn-temperature criterion might account for the lapse. The possibility was anticipated that different burn severities for pigs similarly exposed could occur as a result of different initial skin temperatures. Skin-temperature differences measured on previous nights, as well as on shot night, showed a variation from pig to pig. The pig which had lower skin temperature would be expected to sustain less severe burns. The variability in burns could have been at least partially caused by different initial skin temperatures.

3.5 SHOT HOOD

The maximum temperatures of the skin simulants at the 10,500-foot station for Shot Hood are given in Tables 3.6 and 3.7. The laboratory temperatures quoted are those for 16.3 cal/cm^2 as derived from Figures 3.1 and 3.2 and Table 3.1. Table 3.6 lists the values for the simulant exposed under the screen having a transmission of 0.25. The laboratory temperatures listed for this case are for 4.0 cal/cm^2.

The temperatures for the bare-and-blackened simulants were lower than predicted for both the screened and unscreened exposures. For the cloths in contact the temperatures were as predicted for the unscreened exposures but were considerably higher than expected under the screens. Where the cloths had been spaced the temperatures were as predicted, although modified by the blast so that the excessive erratic temperatures associated with flaming did not occur.

Chapter 4
DISCUSSION

4.1 DATA RELIABILITY

The laboratory experimental error of the maximum skin-simulant temperatures is within 10 percent of the values given in Figure 3.2. Any individual determination of radiant exposure, irradiance or temperature is subject to a maximum error of 5 percent considering the combined calibration and reading errors.

4.2 CORRELATION WITH LABORATORY DATA

A summary of the analysis of the skin-simulant data is given in Table 4.1. The laboratory methods accurately predicted ignition and the consequent high temperatures in all cases, although

TABLE 4.1 SUMMARY OF FIELD AND LABORATORY DATA CORRELATION

Numerical values are in percent except values of t_m and Q; negative values indicate that laboratory data was too high while positive values indicate laboratory data was too low. The affirmatives show that laboratory methods accurately predicted ignition on high temperatures; (B) indicates blast effects.

Shot	Wilson	Priscilla		Hood	
t_m, sec	0.1	0.2	0.2	0.27	0.27
Q, cal/cm^2	17.5	15.0	6.5	16.3	4.0
Bare	−17	−4	—	−26	−3
Blackened	−31	−15	−15	−20	−13
Poplin contact	Yes	Yes	+6	Yes	+38
Sateen contact	Yes	Yes	+4	Yes	+42
Poplin spaced	—	Yes(B)	—	Yes(B)	Yes
Sateen spaced	-	Yes(B)	—	Yes(B)	Yes

in the spaced cloths the blast prevented the attainment of the high temperatures. Laboratory predictions were too high for the uncovered and blackened simulant temperatures. Laboratory predictions were too low for the cloth-covered simulants in contact.

The temperatures of the uncovered and blackened simulants and of the cloth-covered simulants were not predicted as closely as was expected near the important burn level. The discrepancies were expected to be less than 10 percent with the careful calorimetry and instrumentation employed. A possible explanation for the apparent discrepancies stems from the differences in speed with which the heat is transferred into the system and the effect of energy in the later phases of the pulse. Examination of the temperature histories has shown that the uncovered and blackened simulants' temperature maxima occurred at about 1.5 seconds and would probably not be affected by energy arriving after about 1 second or about 4 or 5 t_m. A partial explanation of

the fact that the temperatures recorded at Shots Priscilla and Hood were lower than predicted by the laboratory pulse would be that the field exposures had more energy arriving in the later phases of the pulse used in the laboratory. The temperatures for the cloth-covered simulants in contact peaked at about 5 seconds or 20 t_m and the absence of the energy in the laboratory pulse after 10 t_m may have led to the low predictions.

The predictions of lower temperatures of the cloth-covered simulants behind the 0.9- and 1.7-cm diameter apertures were borne out by the experiment. The adequacy of laboratory methods to determine area effects was demonstrated. The temperatures for the 0.9-cm and 1.7-cm apertures, when the cloth flamed or glowed, should probably be interpreted as a burn indication even though not excessive when whole uniform protection is considered, as pointed up in the laboratory results. The use of the laboratory large-area tungsten source was shown to be adequate to determine area effects within the range of apertures and effects under study. The effects of blast should always be considered when uniform-protection predictions are made from laboratory results; the effects of blast are usually to remove flaming fabrics, reducing burn severities over what would probably be predicted in the laboratory.

There were no systematic differences between results of the uncovered and the blackened simulants, on one hand, and between the simulants under the neutral sateen and under the selective poplin on the other. Therefore, it is believed that the laboratory sources were correct as to spectrum.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

The correlation of skin-simulant temperatures for the six configurations showed that the laboratory methods employing the carbon-arc thermal radiation source and simulated nuclear-weapon pulses were adequate to within 20 percent. The time variation of the irradiance appeared fully adequate and with a more careful consideration of the effect of the later part of the pulse, the remaining laboratory-to-field discrepancy would possibly be reduced.

Since there were no systematic differences between the spectrally selective uncovered simulants and the poplin-covered simulant, and the neutral blackened simulant and the simulant behind the gray sateen, the spectrum of the laboratory carbon-arc thermal source may be considered adequate.

The lower temperatures for the 0.9-cm diameter apertures for cloth contact and also for the 0.9- and 1.7-cm diameter apertures when the cloth was spaced demonstrated the need for careful evaluation of laboratory results when employing these exposure areas. The adequacy of laboratory methods to detect and correct for these discrepancies was shown.

The experimental design as to station locations was successful in that exposures were obtained below as well as above the important burn thresholds.

The skin-simulant temperatures adequately predicted the burns observed on the animals in all cases compared; however, the failure of one recorder at the 12,150-foot station resulted in a loss of two items of skin-simulant data which therefore could not be compared.

5.2 RECOMMENDATIONS

It is recommended that in laboratory investigations of the effects of thermal radiation on materials careful consideration be given to the influence of the later phases of the thermal pulse and its contribution to the total radiant exposure. The effect of employing areas as small as 1.7 cm in diameter should also be considered and the results should be checked, employing larger exposure areas.

In the light of the results of this experiment, investigations of the effects of thermal radiation are best conducted in the laboratory if the conditions are known and can be sufficiently duplicated. Future field tests appear justified only if (1) effects are desired for radiant exposures not obtainable in the laboratory, (2) large areas of parallel radiation are required, (3) the interaction of blast and thermal radiation is important and critical, or (4) it is necessary to verify a laboratory result of important consequence.

Part 2 EFFECTS of THERMAL RADIATION on a STANDARD-REFERENCE MATERIAL

Chapter 6
INTRODUCTION

6.1 OBJECTIVES

The objective of the materials study of Project 8.2 was to determine the adequacy of the laboratory methods employed in studying the effects of intense thermal radiation on materials. More specifically, the purpose of this investigation was to determine the effect of the differences in source parameters (irradiation area, time variation of irradiance, and spectrum) in studying the influence of weapon yield on thermal damage to materials.

6.2 BACKGROUND AND THEORY

Thermal radiation damage to materials has been studied extensively in the laboratory, including the critical radiant exposures required to cause typical damage to representative materials as a function of time of exposure and intensity of irradiation. The purpose of the materials study, as in the case of the skin-simulant study, was to validate the methods employed in the laboratory studies.

Thermal damage to materials has been evaluated at several field tests by NML (References 4, 10, 11) and other agencies for the purpose of correlating the findings with those obtained in the laboratory. These tests have not been conducted under ideal situations; the influence of many exposure and environmental parameters was not sufficiently controlled at the time of the experiments to permit validation of current laboratory procedures. The earlier laboratory experiments were conducted employing constant-irradiance pulses and restricted areas of irradiation. While the correlation experiments indicated that the data drawn from laboratory experiments were significant, an accurate quantitative correlation of the two experiments was impossible because of differences in the size of the irradiated area, moisture content, air supply, spatial orientation, source spectrum, and pulse shape. Recent innovations have been made in the laboratory sources to give a pulse in which the temporal variation of irradiance follows that of a normalized field pulse drawn from the basic thermal radiation measurements made at previous field tests (Reference 12).

A laboratory study has been underway at NML to determine the relationship between the ignition of kindling fuels and these several controllable parameters which affect thermal radiation response. The materials study phase of Project 8.2 was designed to correspond to one set of conditions, which will have been duplicated in the laboratory, permitting correlation of the two sets of data for the purpose of validating a generalized relationship derived from laboratory studies, for the thermal radiation response of cellulosic materials as a function of weapon yield for various source, exposure and environmental parameters.

Chapter 7
PROCEDURE

7.1 OPERATIONS

For its study of macroscopic thermal damage to representative materials, Project 8.2 participated in Shot Priscilla. The materials were exposed at the two major project stations at 7,500 and 12,150 feet. In addition, four minor stations were set at distances of 6,450, 8,400, 9,000 and 10,000 feet from ground zero. The various exposure assemblies were mounted on structures at each station, such structures having been designed to withstand the blast intensities expected at these distances. The various assemblies were recovered as soon after the detonation as practicable.

7.2 INSTRUMENTATION

Alpha-cellulose paper was selected for the study of thermal damage to materials on the basis that it represented an idealized kindling fuel over whose material parameters optimum control could be exercised. It was a material of known density and neutral absorptance, was available in a variety of thicknesses, and was employed in several field and laboratory experiments (References 13 and 14).

Two fabrics, poplin, shade 116, 5 oz/yd^2, and sateen, gray, 9 oz/yd^2, employed in the skin-simulant study, were integrated into this study.

A single sheet of each paper or fabric was mounted behind a thin aluminum sheet with five apertures of four sizes as shown in Figure 7.1. One aperture exposed an edge of the paper (or fabric) to verify the results of a laboratory study of the effect of edge exposures on ignition characteristics. The selection of paper and fabric thicknesses was so made that at least one of the three materials would be ignited at each station. The specimens were enclosed in a sealed metal box with a cover of thin polyvinylidene chloride (Saran). The humidity within the box was maintained at a low value until exposure time by a desiccant enclosed in the sealed box. The transparent plastic cover was blackened near the border of the box so that the Saran border would be destroyed in the initial phase of the thermal pulse, and the rest of the cover would be removed by a loaded spring in about 0.1 second. The material would then be exposed to the principal part of the thermal pulse, allowing free escape of combustion products. The transmittance of the Saran was measured to be 0.90 and essentially neutral spectrally.

The entrance apertures which limited the irradiated areas of the target materials were five circular holes cut in 0.005-inch thick aluminum. The apertures measured 0.9, 1.7, 3.5, and 7.5 cm in diameter. One additional 3.5-cm aperture was used for the study of the effect of edges on determining the critical radiant exposure for ignition. A single sheet of black alpha-cellulose paper was mounted on a 1-inch thick plywood backing with holes drilled through concentric with the entrance apertures but of slightly larger diameter. The larger diameter minimized the influence of the backing. The 0.005-inch thick aluminum sheet with the entrance apertures was laid on the paper. One 3.5-cm aperture contained a semicircle of paper with a cleanly cut edge bisecting the aperture. A flat rigid plate of aluminum, 0.125-inch thick, with holes concentric with, but sufficiently larger than each aperture to assure adequate air supply, was placed over this and the entire assembly was fastened together with wood screws. Figure 7.2 shows the components of an assembly together with a completed assembly. The spectral absorptances of the papers were measured in the range between 0.38 and 2.7 microns. The absorptance was independent of wave length and equal to 0.91. Critical radiant exposures for ignition for each thickness of

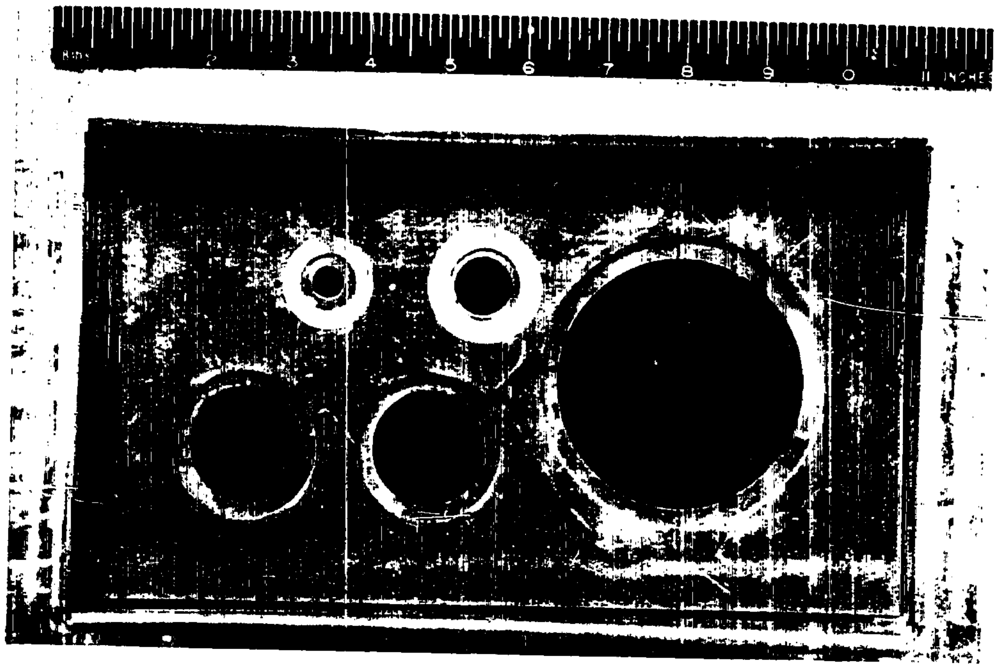


Figure 7 1 Typical exposure assembly for alpha cellulose.

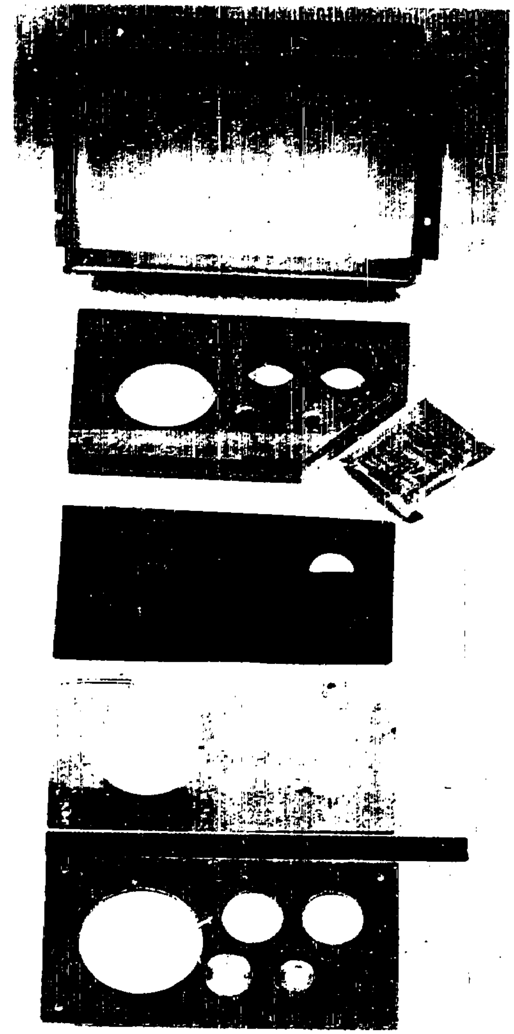


Figure 7.2 Components of alpha cellulose specimen assembly.

paper were determined, using a carbon-arc source with a pulse shape corresponding to a 40-kt detonation. The effects of edge geometry on critical thermal exposure for ignition have also been determined, using the configurations which were exposed in the field. The moisture content of the papers and air supply were maintained as closely as possible to conditions expected at the test site.

7.3 DATA REQUIREMENTS

The data required for the study of thermal damage were derived from two sources, the laboratory and the field. The thermal degradation and ignition of the alpha-cellulose were determined when exposed to thermal radiation under laboratory-controlled conditions. The papers were stored in a desiccator with silica gel and exposed immediately on removal. The exposures were made with a pulse simulating a 40-kt detonation. The ambient temperatures during exposures varied between 22 and 27 C. Relative humidity varied between 20 and 50 percent. Wind velocity in the vicinity of the specimens was negligible during exposure and the air supply to the front of the specimen was not limited. It is expected that these results can be duplicated within ± 10 percent.

The field data were in the form of notes obtained from visual inspection of the damage to materials following exposure to the nuclear device. The disk calorimeters and foil-thermocouple radiometers at the two recording stations provided the associated exposure data consisting of maximum irradiance, time to maximum irradiance, and total radiant exposure. Two types of self-recording calorimeters at each minor station served to provide corrections, if necessitated by local conditions such as possible obscuration and atmospheric attenuation. The effects were compared among themselves and with laboratory results. For complete documentation, a record of temperature, relative humidity, and wind direction and velocity at the test site was provided by other activities.

Chapter 8
RESULTS

8.1 LABORATORY DATA

The critical radiant exposures for charring and ignition of the materials are given in Table 8.1 in terms of field equivalent radiant exposures. Additional pilot work performed using a wide-area tungsten source and square wave pulses indicated that there were no differences in effect due to differences in areas of exposure in the range from 0.9-cm to 7.5-cm diameter or to cleanly cut edges.

8.2 FIELD DATA

Table 8.2 presents the results of examination of the specimens after exposure to Shot Priscilla. The temperature was 17.5 C, the relative humidity was 29 percent, and the air was calm. It was

TABLE 8.1 EFFECTS ON STANDARD-REFERENCE MATERIALS OF EXPOSURE TO LABORATORY CARBON-ARC SOURCE OF THERMAL RADIATION

Material	Density	Thickness	Diameter of Irradiated Area	Critical Charring	Radiant Exposure Ignition or Afterglow
	gms/cm^2	mils	cm	cal/cm^2	cal/cm^2
Alpha	0.75	2.1	0.9	1.8	3.5
Cellulose	0.75	4.1	0.9	3.0	6.1
paper,	0.75	6.1	0.9	4.1	7.9
black	0.75	8.3	0.9	5.2	9.4
	0.75	20.3	0.9	5.5	10
	0.76	31.5	0.9	5.7	27
	0.55	30.3	0.9	3.9	19
Cotton Sateen, dark gray 9 oz/yd^2	—	—	0.9	6.4	12.0
Cotton Poplin, shade 116 5 oz/yd^2	—	—	0.9	9.2	17

difficult to determine thermal effects because the blast removed most of the material from the cavities. However, by examination of the shreds of material remaining, and comparison with the remains of similar materials which had been exposed in the laboratory, it was possible to determine the occurrence of charring and the probability of ignition in each cavity.

Traces of charred material were found in every aperture, which was in keeping with the design of the experiment. Where the material was removed cleanly to the edge of the aperture plate, it was deduced that ignition had occurred and had gone to completion, and the result was reported as ignition probable.

Where shreds of material with torn ragged edges remained in the aperture it was deduced that ignition had not occurred, and the result was reported as ignition improbable.

TABLE 8.2 EFFECTS OF THERMAL RADIATION ON STANDARD-REFERENCE MATERIALS, SHOT PRISCILLA

Radiant Exposure	Material	Diameter of Aperture	Effect Predicted from Laboratory Data	Observed Effect	Laboratory Radiant Exposure for Observed Effect
cal/cm^2		cm			cal/cm^2
6,450-foot Station:					
21	Poplin, shade 116, 5 oz/yd^2	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain, * ignition probable † in all apertures	17
	Alpha-cellulose, black, density 0.55, thickness 30.3 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain, * ignition improbable ‡ in all apertures	19
	Alpha-cellulose, black, density 0.75, thickness 31.5 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain, * ignition improbable ‡ in all apertures	5.7 to 27
7,500-foot Station:					
15	Sateen, dark gray, 9 oz/yd^2	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain, * ignition probable † in all apertures	12
	Poplin, shade 116, 5 oz/yd^2	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain, * ignition probable † in all apertures	17
	Alpha-cellulose, black, density 0.55, thickness 30.3 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain, * ignition improbable ‡	3.9 to 19
8,400-foot Station:					
13	Alpha-cellulose, black, density 0.75, thickness 20.3 mils	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain, * ignition improbable ‡ in all apertures	5.5 to 10
	Sateen, dark gray, 9 oz/yd^2	0.9 1.5 3.5 3.5 (edge) 7.5	Ignition	Charring certain, * ignition uncertain § in all apertures	6.4 to 12
	Poplin, shade 116, 5 oz/yd^2	0.9 1.5 3.5 3.5 (edge) 7.5	Charring	Charring certain, * ignition improbable † in all apertures	9.2 to 17

CONFIDENTIAL

TABLE 8.2 CONTINUED

Radiant Exposure	Material	Diameter of Aperture	Effect Predicted from Laboratory Data	Observed Effect	Laboratory Radiant Exposure for Observed Effect
cal/cm^2		cm			cal/cm^2
9,000-foot Station:					
10	Alpha-cellulose,	0.9	Ignition	Charring certain,*	9.4
	black, density	1.5		ignition probable †	
	0.75, thickness	3.5		in all apertures	
	8.3 mils	3.5 (edge)			
		7.5			
	Alpha-cellulose,	0.9	Ignition	Charring certain,*	5.5 to 10
	black, density	1.5	(critical)	no ignition§ in	
	0.75, thickness	3.5		all apertures	
	20.3 mils	3.5 (edge)			
		7.5			
	Sateen, dark	0.9	Charring	Charring certain,*	6.4 to 12
	gray, 9 oz/yd^2			ignition improbable ‡	
		1.5		Charring certain,*	
				ignition uncertain ¶	
		3.5		Charring certain,*	
				ignition uncertain ¶	
		3.5 (edge)		Charring certain,*	
				ignition probable †	
		7.5		Charring certain,*	
				ignition uncertain ¶	
10,000-foot Station:					
8.5	Alpha-cellulose,	0.9	Ignition	Charring certain,*	7.9
	black, density	1.5		ignition probable †	
	0.75, thickness	3.5		in all apertures	
	6.1 mils	3.5 (edge)			
		7.5			
	Alpha-cellulose,	0.9	Charring	Charring certain,*	5.2 to 9.4
	black, density	1.5		ignition improbable ‡	
	0.75, thickness	3.5		in all apertures	
	8.3 mils	3.5 (edge)			
		7.5			
	Alpha-cellulose,	0.9	Ignition	Charring certain,*	6.1
	black, density	1.5		ignition probable †	
	0.75, thickness	3.5			
	4.1 mils	3.5 (edge)			
		7.5			
12,150-foot Station:					
6.5	Alpha-cellulose,	0.9	Ignition	Charring certain,*	6.1
	black, density	1.5		ignition probable †	
	0.75, thickness	3.5		in all apertures	
	4.1 mils	3.5 (edge)			
		7.5			
	Alpha-cellulose,	0.9	Charring	Charring certain,*	4.1 to 7.9
	black, density	1.5		ignition improbable ‡	
	0.75, thickness	3.5		in all apertures	
	6.1 mils	3.5 (edge)			
		7.5			
	Alpha-cellulose,	0.9	Charring	Charring certain,*	5.2 to 9.4
	black, density	1.5		ignition improbable ‡	
	0.75, thickness	3.5		in all apertures	
	8.3 mils	3.5 (edge)			
		7.5			

* Observation of charring certain based on charred edges or shreds around aperture.

† Observation of ignition probable based on material being removed cleanly up to aperture edge with sooty residue under aperture plate.

‡ Observation of ignition improbable based on ragged edges and shreds of material left in aperture.

¶ Observation of ignition uncertain based on occasional unburned threads protruding from aperture edge.

§ Observation of no ignition based on large residue of partially charred, unconsumed material.

In apertures whe[illegible]ss cotton fabrics had been mounted and ignition might possibly have occurred, the presenc[illegible] of unapparent threads jutting into the aperture led to the observation of ignition uncertain.

At the 9,000-foot s[illegible]tation the charred remains of the 20.3 mil thick alpha-cellulose were left intact in the apertures [illegible] a definite conclusion of no ignition was reported.

Any small differenc[illegible] which might have existed in thermal effects due to aperture size were obscured by blast effec[illegible] [illegible] the 3,500-foot station, a possible difference appeared in the effects on dark gray sateen [illegible] and 3.5 (edge) apertures. However, the other apertures contained some unconsumed thr[illegible]ads, together with traces of soot, so that an estimate that ignition had occurred in this materia[illegible] was in doubt. Since no other specimens showed effects varying with area no conclusions were d[illegible]awn from the apparent differences in this case. The data from the other five stations indicated [illegible]hat there were no differences in effect due to differences in exposure area or the presence of cle[illegible]anly cut edges. Environmental differences that may have existed between the laboratory and fiel[illegible] exposures made no apparent difference.

Eighteen basic expo[illegible]re situations were used, namely three materials at each of six stations. One situation, the sat[illegible] at the 8,400-foot station, yielded no data. Two situations yielded data in disagreement with t[illegible]hat predicted from laboratory results. At the 6,450-foot station, the 30.3-mil-thick alpha-cellulo[illegible]e was judged not to have ignited for an exposure of 21 cal/cm², whereas the laboratory exposur[illegible] predicted ignition at 19 cal/cm². At the 8,400-foot station, the 20.3-mil-thick alpha-cellulose [illegible]s not ignited for an exposure of [illegible]3 cal/cm², and the laboratory results indicated ignition at 10[illegible] cal/cm². In fifteen of the eighteen situations, the field results were in agreement with predic[illegible]ions made from laboratory results.

Motion pictures of t[illegible]he specimens made at the 7,500-foot and 12,150-foot stations yielded no further information that [illegible] could be used to change or modify judgments made as to ignition.

Chapter 9
DISCUSSION

9.1 DATA RELIABILITY

The laboratory data given for charring and ignition was considered reproducible to within ± 10 percent.

In spite of the difficulty of observation of thermal effects due to removal of remnants by blast the observation of charring could be made with certainty, as could the deduction of ignition where soot remained under the edges of the aperture plates. The observations of no ignition, ignition improbable, or ignition uncertain were more doubtful since ignition may have been terminated by the blast.

9.2 CORRELATION WITH LABORATORY DATA

No apparent contradictions between laboratory effects and field effects existed except at the 6,450-foot station, and at the 8,400-foot station. The 30.3-mil-thick alpha-cellulose at the 6,450-foot station was presumed to have not ignited from examination of the residue. Since the laboratory exposure for ignition was 19 cal/cm^2 and the exposure at the station was 21 cal/cm^2, there was the possibility that ignition had started and had not gone to completion when the blast arrived. The same possibility existed for the case of the 20.3-cal/cm^2 alpha-cellulose paper at the 6,450-foot station. Both these papers were relatively thick and required several seconds for ignition to go to completion, in which time the blast could have removed the material from the cavity.

At the 8,400-foot station, the uncertainty in reading the results on the dark gray sateen precluded a firm judgment as to the correlation between laboratory and field results at this station.

Comparison of results at the 7,500-foot, 9,000-foot, 10,000-foot, and 12,150-foot stations with critical values for ignition found in the laboratory indicated that the radiant exposure delivered in the field would have produced the same results as an equivalent radiant exposure using the laboratory source. In addition, if the effects produced on the materials by laboratory exposures were taken as indications of the radiant exposures received by the materials, then the effects produced in the field indicated differences from field calorimetry of between 6 and 22 percent at these four stations. The difference in ambient conditions that existed during laboratory exposures and exposures to Shot Priscilla were small and were further minimized by the precautions taken in each case to insure immediate exposure of the materials on removal from the controlled atmosphere. Therefore, the effect of these possible variables need not be considered in the correlation.

Chapter 10
CONCLUSIONS and RECOMMENDATIONS

10.1 CONCLUSIONS

The data yielded by examination of the materials exposed to Shot Priscilla indicated that the laboratory methods employed by NML for studying ignition of cellulose materials would yield qualitative data that was within 25 percent of expected field data. The results indicated that no special consideration need be given to problems of area of exposure and edge effects for pulses approximately those of a 40-kt nuclear detonation. The NML carbon-arc source generated a pulse that was adequate in its time-irradiance and spectral characteristics to reproduce charring and ignition effects that would be caused by kiloton-range detonations on materials with simple target geometries.

10.2 RECOMMENDATIONS

The study of the effects of thermal radiation from nuclear detonations on most materials, especially cellulosic materials, is best carried out in the laboratory, where experimental conditions are more readily controlled, and where more data may be generated for an identical effect. Blast effects in the field, which tend to confuse the interpretation of thermal radiation effects, can be eliminated only with difficulty. The simpler safeguards required to eliminate undesirable blast effects can be expected to introduce further complications such as limiting air supply and to create atypical heat-flow situations. For simple target geometries, which are of general interest in material studies, laboratory studies are more likely to lead to adaptable generalizations over a wider range of exposure parameters which can be controlled at will.

Thermal radiation problems involving complex target geometries, structural qualities, high irradiances such as those encountered in the vicinity of ground zero, and those involving blast-thermal interaction effects, are more difficult to handle in the laboratory because of the small size and limited output of available laboratory thermal radiation sources and the difficulties in producing simultaneously blast, ionizing radiation, and thermal radiation.

Appendix
BASIC THERMAL MEASUREMENTS

A.1 BACKGROUND AND THEORY

In order to draw quantitative conclusions from a study of thermal effects during a full-scale nuclear-test operation, it is essential to determine the radiant exposure and variation of irradiance with time at the thermal-effect stations. Because of possible obscuration by dust clouds and other local disturbances, measurements of radiant exposure are desirable at the individual stations. Recording equipment was used in Operation Plumbbob to make such measurements with calorimeters and radiometers similar to those which have been used by Naval Material Laboratory (NML) and the U. S. Naval Radiological Defense Laboratory (NRDL) in previous operations. The recording copper-disk calorimeters consisted essentially of a blackened copper disk, approximately 1 cm in diameter, to which a thermocouple was attached. The radiant-exposure value was computed directly from the temperature history of the button, corrected for the losses occurring during an exposure. The radiometers were thin, blackened, constantan-foil receivers soldered over a small hole in a copper-block heat sink. A fine copper or iron wire, attached to the back of the foil in the center of the hole in the heat sink, allowed the recording of the temperature of the foil, which was proportional to the irradiance.

Where such equipment was not available, passive calorimeters were employed, such as those which NML has employed in previous field tests. These instruments were self-recording and did not require auxiliary power for their operation. Of the passive-type calorimeters that have been used by NML (meter-foil indicators, cylindrical-paper indicators and plane-paper indicators), the metal-foil type was selected as most suitable for meeting the present requirements. The metal-foil calorimeters, with slight variations in design, were used by NML in Operations Greenhouse, Buster-Jangle, and Upshot-Knothole, to give radiant-exposure values and, when exposed behind filters, to give an estimate of the spectral-energy distribution. The basic unit, shown in Figure A.1, consisted of a series of foil strips, of several metals and various thicknesses and absorptances, suspended over an air background. Upon subjection to a given thermal impulse, certain of the foils melted or suffered other levels of degradation; on the basis of a calibration in the laboratory, the thermal degradation of a given foil could be translated into the receipt of a minimum amount of thermal flux at that station.

In addition to the foil calorimeters, NML in Plumbbob employed a newly developed, self-contained calorimeter. The design features of this instrument, designated the thermal-radiant-exposure meter (TREM), afforded greater flexibility and permited fabrication of a series of units covering a much wider range of radiant exposures than heretofore possible and with a finer resolution throughout the range. The essential parts of the meter were a copper plate of uniform thickness, blackened on the face upon which the radiation was incident. Against the other side was placed, in point contact, a series of pellets with precise melting temperatures. These pellets were obtainable over a wide range of temperatures at intervals of approximately 7 C. As shown in Figure A.2, this assembly was housed in a transparent, air-tight, plastic box containing a quartz window to admit radiation. A reading was taken after exposure by observation, through the clear container, as to which was the last in the series of pellets to have melted at the point of contact with the copper plate (Figure A.3). Laboratory calibration of the TREM indicated that the temperature of the copper plate could be computed from the physical parameters of the situation by the use of the measured loss rates. Details of the design, construction, and calibration of the TREM are given in a report on the instrument (Reference 15). The various components of the meter are shown in Figure A.4.

A.2 INSTRUMENTATION

The primary measurement of radiant exposure and irradiance for Project 8.2 was provided by three disk-type calorimeters and a foil radiometer at each of the two major Shot Priscilla stations and at the Shot Hood Station. These devices generated a thermoelectric voltage under influence of thermal radiation, and these signals were recorded oscillographically. The electrical instruments were mounted at a height of 7 feet. For Shot Priscilla, self-contained metal-foil calorimeters were mounted at each of the stations of Projects 4.1, 8.1, and 8.2. At the stations of Projects 4.1 and 8.1, the instruments were mounted at the level of the exposed animal; at the NML stations of Project 8.2, these metal-foil calorimeters were placed at the height of the specimens and the recording calorimeters. Two metal-foil instruments were mounted at each location, one behind a neutral attenuating screen to assure a response in a region of

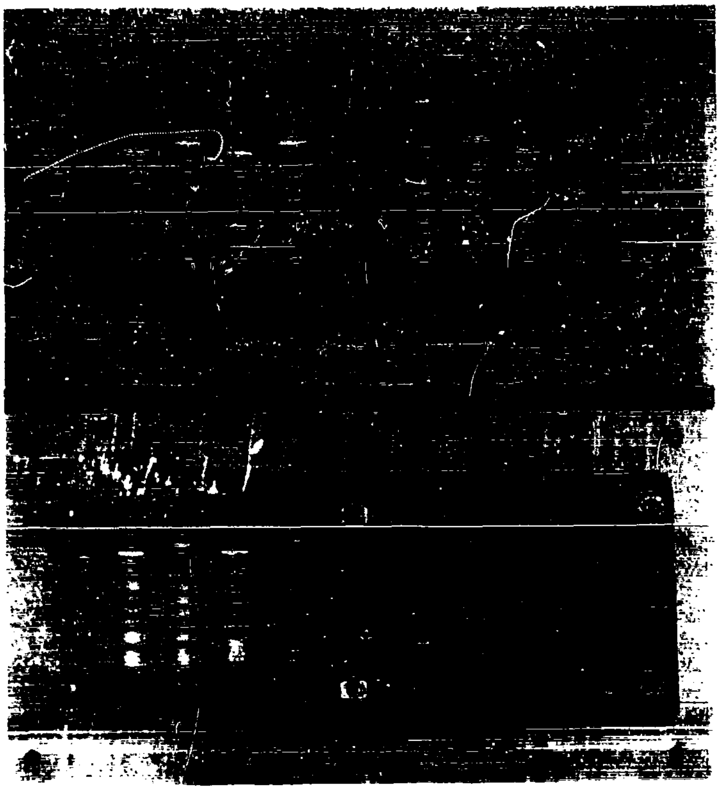


Figure A.1 Naval Material Laboratory foil calorimeter with and without attenuating screen.

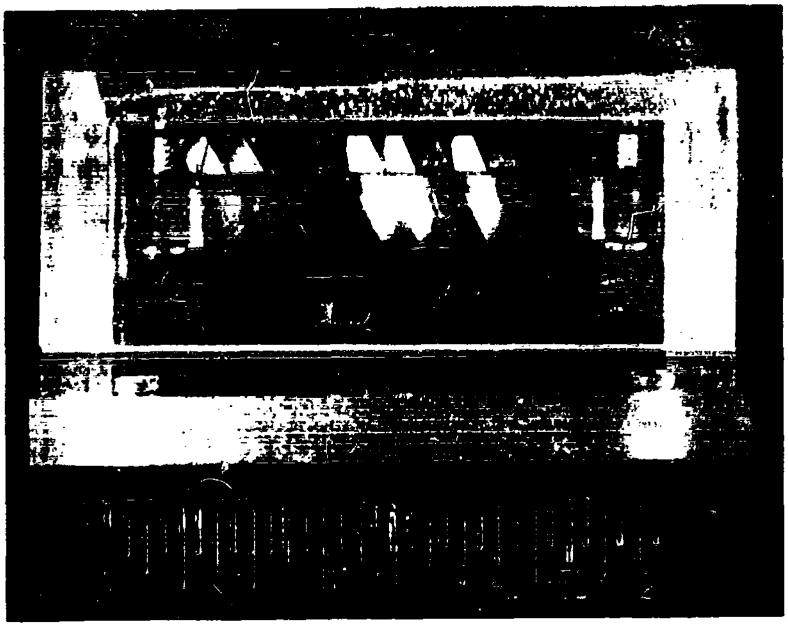


Figure A.2 Naval Material Laboratory thermal radiant exposure meter.

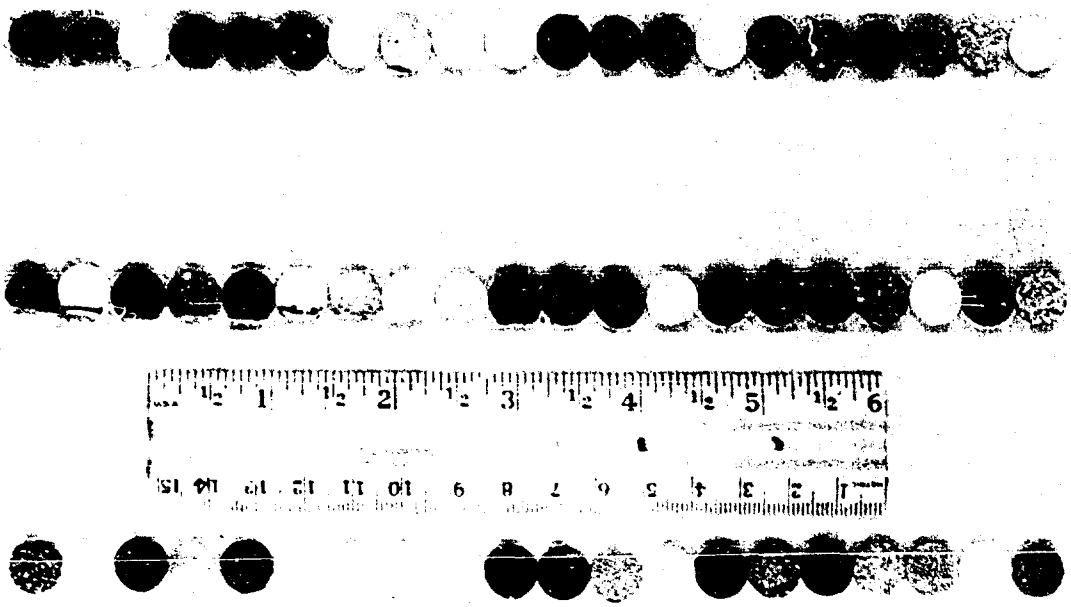


Figure A.3 Melted pellets from an exposed thermal radiant exposure meter.

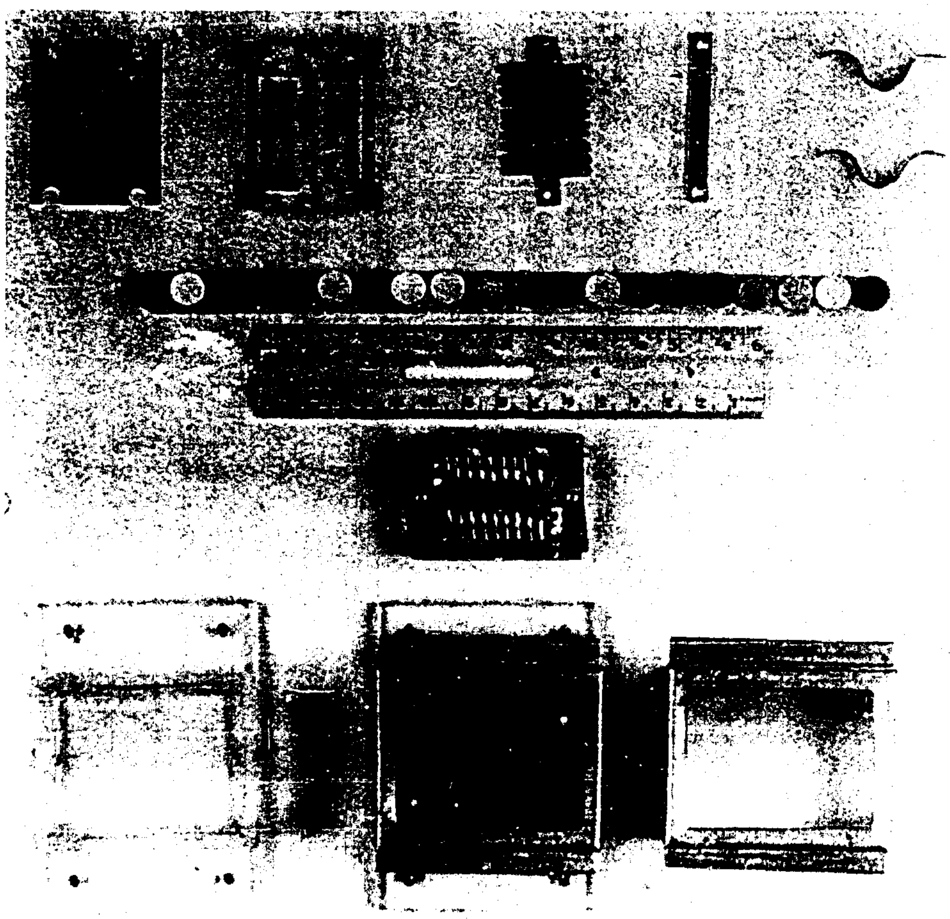


Figure A.4 Components of the NML thermal radiant exposure meter.

optimum resolution. The indications at the recording stations were employed to check the calibration of the metal-foil calorimeters.

The copper-plate-pellet thermal-radiant-exposure meters were placed at each location where the other calorimetric devices were employed. In addition, the meters were placed at distances of 10,000, 27,000, 37,000 and 50,000 feet to document more completely the relationship between radiant exposure and distance. At the recording stations, the temperature histories of the copper plates of several TREMS were measured to provide additional calibrations.

TABLE A.1 THERMAL RADIATION MEASUREMENTS, SHOT WILSON, 3,965 FEET

Foil Meter		Radiometer			Calorimeter			Copper Plate			
								Pellet	Electrical		
Screen Transmission	Radiant Exposure	Q	H_m	t_m	Q	H_m	t_m	Q	Q	H_m	t_m
	cal/cm^2	cal/cm^2	$(cal/cm^2)/sec$	sec	cal/cm^2	$(cal/cm^2)/sec$	sec	cal/cm^2	cal/cm^2	$(cal/cm^2)/sec$	sec
—	21	17.6	69	0.105	17.6	59	0.114	15	15.4	54	0.114
—	22	17.5	65	0.107	16.6	55	0.110	14	11.2 *	52	0.105
0.45	15	—	—	—	—	—	—	13	13.2 †	55	0.104
0.45	15	—	—	—	—	—	—	15	—	—	—

* Under screen with a 0.14 transmission.
† Under screen with a 0.037 transmission.

TABLE A.2 THERMAL RADIATION MEASUREMENTS, SHOT WILSON, PROJECT 4.1 STATIONS

Slant Distance	Copper Plate Meter		Foil Meter	
	Screen Transmission	Radiant Exposure	Screen Transmission	Radiant Exposure
ft		cal/cm^2		cal/cm^2
2,590	0.48	29	—	—
	0.48	27	—	—
2,720	—	29	—	29
	—	31	0.073	34
2,920	—	23	—	—
	—	23	—	—
3,495	—	20	-	23
	—	21	0.14	19

A.3 RESULTS

A.3.1 Shot Lassen. No deflections were recorded on any of the calorimetric and radiometric equipment. The sensitivities of the calorimeters were such that the radiant exposure at the distance of 3,930 feet from ground zero (slant distance of 3,960 feet) was significantly less than 0.008 cal/cm^2.

A.3.2 Shot Wilson. The thermal-radiation measurements made at the Project 8.2 station are summarized in Table A.1. The results of the electrical measurements on the copper plates of the TREMS are also included. The radiant exposures listed for the radiometers represent the integration of the irradiance history determined by the instrument. The irradiances listed for the calorimeters resulted from a differentiation of the radiant-exposure histories. It will be noted that the values indicated by the copper plates are lower than the other instruments; the reason for this is not known and is being investigated at the present time. Since these are recently developed instruments and were used for the first time in this operation, the value of 17.5 cal/cm^2 for the radiant exposure for this station was obtained using the data of the standard radiometers and calorimeters normally employed in these measurements.

The average irradiance maximum measured by the two radiometers was 67 $(cal/cm^2)/sec$ which is significantly greater than the 58 $(cal/cm^2)/sec$ average of the two standard calorimeters. The time to second maximum measured by the radiometers was 106 msec compared to 112 msec for the calorimeters.

The irradiance histories as measured by the radiometers and calorimeters were analyzed. The average of the histories was essentially that of the generalized pulse (see Reference 12) as given up to 10 t_m. At 15,

20, 25 and 30 t_m the irradiances relative to that at the second maximum were 0.03, 0.025, 0.015 and 0.005 respectively.

The radiant exposures at each of the Project 4.1 stations instrumented during Shot Wilson are given in Table A.2. It is to be noted that the radiant exposure at 2,590 feet is not appreciably greater than that at 2,720 feet. The areas in front of all the 4.1 stations were not stabilized; popcorning of the sand and other obscurating factors caused by blast may have accounted for the reduction in radiant exposure.

A.3.3 Shot Priscilla. The thermal-radiation determinations at the two recording stations are given in Table A.3, as are the readings of the self-recording radiant-exposure meters. Table A.4 lists the readings of the thermal-radiant-exposure meters placed at the stations of Project 4.1, and Table A.5 lists the radiant-exposure measurements obtained for Project 8.1.

The descrepancies among the recording instruments were disappointing. There was agreement on t_m of 0.20 among the calorimeters as against the average of 0.17 for the radiometers, the lower value for the radiometer being consistent with the Shot Wilson Measurements. The irradiance maxima were in good agreement except for the one TREM giving an erratic trace.

The radiant-exposure readings of the foil meters under the screens were evidently low. Dust in the fine screens employed may have accounted for the discrepancies between the screened and unscreened values. The transmittance of the various screens and screen combinations had been determined by the use of sunlight and a receiver cell placed at the position of the foil receivers. The transmittances were considered to be correct to within 5 percent.

Upon postshot examination of the three close-in stations of Project 4.1, it was noted that the quartz windows of the TREMS had been removed and the instruments were filled with dirt. The front-window retaining plate showed evidence of surface melt and missile damage. The indicating pellets, however, were intact and were believed to indicate correctly the energy actually received by the copper receiving plate. The readings of these close-in receivers were lower than those predicted by normal distance relationships but may possibly be explained if one assumes no thermal radiation after the arrival of the blast wave due to dust and debris raised by the shock.

Because of discrepancies among data obtained at the same height, it is difficult to compute a reliable difference in radiant exposure between $3\frac{1}{2}$ feet where the animals of Project 8.1 were placed and the 7 feet where the recording measurements were made and where the Project 8.2 specimens were placed. However, a definite difference (which was judged to be about 10 percent) seemed to exist.

The irradiance histories of Shot Priscilla were analyzed. The irradiance was higher than that of the generalized pulse by 10 to 20 percent from 1.5 to about 9 times t_m. The irradiance after 10 t_m was

TABLE A.3 THERMAL RADIATION MEASUREMENTS, SHOT PRISCILLA, PROJECT 8.2 STATIONS

Slant Distance	Copper Plate Meter: Pellet	Copper Plate Meter: Electrical			Foil Meter		Radiometer			Calorimeter		
	Q	Q	H_m	t_m	Screen Transmission	Q	Q	H_m	t_m	Q	H_m	t_m
ft	cal/cm²	cal/cm²	(cal/cm²)/sec	sec		cal/cm²	cal/cm²	(cal/cm²)/sec	sec	cal/cm²	(cal/cm²)/sec	sec
6,490	24	—	—	—	—	—	—	—	—	—	—	—
	21	—	—	—	—	—	—	—	—	—	—	—
7,540	18	18.9 *	43 *	0.20	—	21	12.0	27	0.16	16.3	26.5	0.20
	17	13.2	28	0.20	0.15	8	—	—	—	13.8	27.5	0.21
8,440	13	—	—	—	—	9	—	—	—	—	—	—
	—	—	—	—	0.15	8	—	—	—	—	—	—
[illegible]	10	—	—	—	—	—	—	—	—	—	—	—
10,225	9	—	—			8	—	—	—	—	—	—
	—	—	—	—	0.15	6.5	—	—	—	—	—	—
12,170	4.3	5.5	—	—	—	5	6.7	12.0	0.18	6.4	11	0.20
	5.3	—	—	—	0.48	4.5	—	—	—	—	—	—
	4.3	—	—	—	—	—	—	—	—	—	—	—
19,020	1.8	—	—	—	—	—	—	—	—	—	—	—
	1.8	—	—	—	—	—	—	—	—	—	—	—
27,000	0.89	—	—	—	—	—	—	—	—	—	—	—
	1.22	—	—	—	—	—	—	—	—	—	—	—
37,000	0.49	—	—	—	—	—	—	—	—	—	—	—
	0.49	—	—	—	—	—	—	—	—	—	—	—
50,000	0.45	—	—	—	—	—	—	—	—	—	—	—
	0.43	—	—	—	—	—	—	—	—	—	—	—

* Poor trace quality.

TABLE A.4 THERMAL RADIATION MEASUREMENTS, SHOT PRISCILLA, PROJECT 4.1 STATIONS

Slant Distance	Copper Plate Meter: Screen Transmission	Copper Plate Meter: Radiant Exposure	Foil Meter: Screen Transmission	Foil Meter: Radiant Exposure	Most Probable Value
ft		cal cm²		cal cm²	cal cm²
2,720	0.55	92 *	—	—	90
	—	< 121	—	—	—
2,820	0.55	76 *	—	†	75
	—	< 91	—	—	—
3,085	—	80 *			75
	0.55	70		—	—
3,995	—	—	—	—	—
4,210	—	60	0.095	49	60
	—	—	0.048	47	—
4,450	—	40	—	—	40
4,820	—	45	—	—	45
5,390	—	—	—	—	—
6,160	—	22	—	21	21
	—	—	0.095	12	—
7,860	—	14	—	—	15
	—	17	—	—	—
9,520	—	—	—	—	—

* The windows of these instruments were broken and sand was embedded in the receiving plate.

† Instruments were destroyed by missiles.

TABLE A.5 THERMAL RADIATION MEASUREMENTS, SHOT PRISCILLA, PROJECT 8.1

Slant Distance	Recording Meter	Copper Plate Meter, Pellets	Foil Meter: Screen Transmission	Foil Meter: Radiant Exposure
ft	cal cm²	cal cm²		cal/cm²
5,559	—	24	—	23
	—	—	0.095	16
6,499	—	21	—	21
	—	—	0.095	9
[illegible]	16.5	15	—	19
	13.5	—	0.145	10
[illegible]	—	10	—	8
	—	—	0.145	6.5
[illegible]	6.7	4.9	—	5
	6.4	—	0.48	4

TABLE A.6 THERMAL RADIATION MEASUREMENTS, SHOT HOOD

Radiometer: Q	Radiometer: H_m	Radiometer: t_m	Calorimeter: Q	Calorimeter: H_m	Calorimeter: t_m	Copper Plate Meter, Pellet: Q	Copper Plate Meter, Electrical: Q	Copper Plate Meter, Electrical: H_m	Copper Plate Meter, Electrical: t_m
cal/cm²	(cal/cm²)/sec	sec	cal/cm²	(cal/cm²)/sec	sec	cal/cm²	cal/cm²	(cal/cm²)/sec	sec
15.8	25	0.27	15.6	25	0.27	13.8 †	13.0 †	22 †	0.275
—	—	—	[illegible]	23	0.27	13.6	11.5	21	0.26
—	—	—	14.5	24 *	0.28	13.9	—	—	—
Under screen with skin-simulants:									
3.9	3.7	0.27	4.2	[illegible]	0.27	—	—	—	—
—	—	—	3.9	5.9	0.26	—	—	—	—

* With excluding tube.

† Corrected for 0.48 screen transmission.

similar to that for Shot Wilson.

The radiant exposures indicated by the calorimeters were considered to be the most reliable. At the 7,500 and 12,150-foot stations, employed for the skin-simulant studies, the radiant exposures were 15 and 6.5 cal cm^2, respectively.

A.3.4 Shot Hood. The thermal radiation measurements obtained at the station at 10,500 feet in Shot Hood without and behind the screens are given in Table A.6. The standard calorimeters indicated a radiant exposure at the station of 16.3 cal cm^2 with 4.1 cal cm^2 under the screen. The screen transmittance, determined by the ratio of the values with and without the screen, was 0.25. To check on the portion of the thermal radiation reflected from the ground, a tube was placed on one of the calorimeters. The tube was 5.9 cm in diameter and extended 33 cm in front of the 0.9-cm-diameter copper disk, giving the center of the button an angle of view of 10 degrees. The fraction of thermal energy excluded by the tube was 11 percent.

The low irradiance indicated by the radiometer under the screen was probably caused by the obscuration of the small sensitive area of the radiometer by the screen wire.

The irradiance history for Shot Hood was shown to have a 5 percent greater irradiance than the generalized curve over the region of 1.5 to 1.7 t_m and to have a 10 percent less irradiance in the region from 6 to 10 t_m. The irradiance after 10 t_m was relatively less than for Shots Wilson and Priscilla; for relative times of 15, 20, 25 and 30 t_m it was 0.02, 0.015, and 0.005 of the irradiance maximum.

REFERENCES

1. W. L. Derksen, W. J. Bates and T. I. Monahan; "The Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics"; Lab Project 5046-3, Part 42, November 1954; Naval Material Laboratory, Brooklyn, New York; Unclassified.

2. T. D. Murtha, W. L. Derksen and T. I. Monahan; "A Method to Improve the Optical Characteristics of the Black Polyethylene Skin Simulant"; Lab Project 5046-3, Part 78, 25 March 1955; Naval Material Laboratory, Brooklyn, New York; Unclassified.

3. R. C. Maggio; "A Molded Skin Simulant with Thermal and Optical Constants Approximating those of Human Skin"; Lab Project 5046-3, Part 105, 23 August 1956; Naval Material Laboratory, Brooklyn, New York; Unclassified.

4. T. I. Monahan and W. L. Derksen; "Effects of Thermal Radiation on Materials"; Project 8.9, Operation Upshot-Knothole, WT-772, May 1954; Naval Material Laboratory, Brooklyn, New York; Confidential Formerly Restricted Data.

5. T. I. Monahan and W. L. Derksen; "A Review of the Development of a Plastic Physical Skin Simulant for Evaluating Sub-Fabric Flash Burns"; Lab Project 5046-3, Part 84, 22 July 1955; Naval Material Laboratory, Brooklyn, New York; Unclassified.

6. G. Mixter, Jr., T. P. Davis and H. E. Pearse; "The Sub-Fabric Flash Burn: Quantitative Effect on Protectivity of Fabric Weight and Exposure Time"; UR-386, 6 June 1955; University of Rochester, Rochester, New York; Unclassified.

7. K. M. Berkley, H. E. Pearse and T. P. Davis; "Studies of Flash Burns: the Influence of Skin Temperature in the Production of Cutaneous Burns in Swine"; UR-338, 5 August 1954; University of Rochester, Rochester, New York; Unclassified.

8. J. J. Bates, J. A. Carter and T. I. Monahan; "The Thermal and Optical Characteristics of Nevada Sand"; Lab Project 5046-3, Part 19, 12 May 1952; Naval Material Laboratory, Brooklyn, New York; Confidential.

9. M. J. Kelly and H. Korbel; "Reflection of ABD Thermal Radiation by a Diffusing Ground Surface"; Lab Project 5046-3, Part 28, 5 November 1952; Naval Material Laboratory, Brooklyn, New York; Confidential.

10. A. Broido and others; Naval Radiological Defense Laboratory, San Francisco, California; J. M. McGreevy and others; Naval Material Laboratory, Brooklyn, New York; "Effect of Thermal Radiation on Material"; Project 6.2, Operation Greenhouse, WT-70, September 1951; Unclassified.

11. T. I. Monahan; "Effects of Thermal Radiation on Materials"; Project 2.4-2, Operation Buster-Jangle, WT-311, May 1952; Naval Material Laboratory, Brooklyn, New York; Unclassified.

12. L. B. Streets; "The Basic Characteristics of Thermal Radiation of an Atomic Detonation"; AFSWP 503, November 1953; Armed Forces Special Weapons Project, Washington, D. C.; Secret Restricted Data.

13. W. L. Fons, C. P. Butler and H. D. Bruce; "Thermal Effects on Cellulosic Materials"; Project 8.2, Operation Redwing, ITR-1339, June 1956; U.S. Department of Agriculture, Forest Service, Division of Fire Research, Berkeley, California; Confidential.

14. F.M. Sauer; "Ignition of Black Alpha-Cellulose Papers by Thermal Radiation – Square Wave Pulse"; Interim Technical Report AFSWP-869, September 1956; U.S. Department of Agriculture, Forest Service, Division of Fire Research, Berkeley, California; Unclassified.

15. W.L. Derksen, A. Hirschman and T.I Monahan; "A Self-Recording Thermal-Radiation-Exposure Meter"; Lab Project 5046-3, Part 109 (to be published); Naval Material Laboratory, Brooklyn, New York; Unclassified.

DISTRIBUTION

Military Distribution Category 82

ARMY ACTIVITIES

1 Deputy Chief of Staff for Military Operations, D/A, Washington 25, D.C. ATTN: Dir. of SW&R
2 Chief of Research and Development, D/A, Washington 25, D.C. ATTN: Atomic Div.
3 Assistant Chief of Staff, Intelligence, D/A, Washington 25, D.C.
4- 5 Chief Chemical Officer, D/A, Washington 25, D.C.
6 Chief of Engineers, D/A, Washington 25, D.C. ATTN: ENGNB
7 Chief of Engineers, D/A, Washington 25, D.C. ATTN: ENGEB
8 Chief of Engineers, D/A, Washington 25, D.C. ATTN: ENGTB
9- 10 Office, Chief of Ordnance, D/A, Washington 25, D.C. ATTN: ORDTN
11 Chief Signal Officer, D/A, Plans, Programs, and Ops. Div., Washington 25, D.C. ATTN: SIGOP-7A
12 The Surgeon General, D/A, Washington 25, D.C. ATTN: MEDNE
13- 15 Commanding General, U.S. Continental Army Command, Ft. Monroe, Va.
16 Director of Special Weapons Development Office, Headquarters CONARC, Ft. Bliss, Tex. ATTN: Capt. Chester I. Peterson
17 President, U.S. Army Artillery Board, Ft. Sill, Okla.
18 President, U.S. Army Infantry Board, Ft. Benning, Ga.
19 President, U.S. Army Air Defense Board, Ft. Bliss, Tex.
20 President, U.S. Army Aviation Board, Ft. Rucker, Ala. ATTN: ATBG-DG
21 Commandant, U.S. Army Command & General Staff College, Ft. Leavenworth, Kansas. ATTN: ARCHIVES
22 Commandant, U.S. Army Air Defense School, Ft. Bliss, Tex. ATTN: Command & Staff Dept.
23 Commandant, U.S. Army Armored School, Ft. Knox, Ky.
24 Commandant, U.S. Army Artillery and Missile School, Ft. Sill, Okla. ATTN: Combat Development Department
25 Commandant, U.S. Army Aviation School, Ft. Rucker, Ala.
26 Commandant, U.S. Army Infantry School, Ft. Benning, Ga. ATTN: C.D.S.
27 The Superintendent, U.S. Military Academy, West Point, N.Y. ATTN: Prof. of Ordnance
28 Commandant, The Quartermaster School, U.S. Army, Ft. Lee, Va. ATTN: Chief, QM Library
29 Commandant, U.S. Army Ordnance School, Aberdeen Proving Ground, Md.
30 Commandant, U.S. Army Ordnance and Guided Missile School, Redstone Arsenal, Ala.
31 Commanding General, Chemical Corps Training Comd., Ft. McClellan, Ala.
32 Commandant, USA Signal School, Ft. Monmouth, N.J.
33 Commanding General, The Engineer Center, Ft. Belvoir, Va. ATTN: Asst. Cmdt, Engr. School
34 Director, Armed Forces Institute of Pathology, Walter Reed Army Med. Center, 625 16th St., NW, Washington 25, D.C.
35 Commanding Officer, Army Medical Research Lab., Ft. Knox, Ky.
36 Commandant, Walter Reed Army Inst. of Res., Walter Reed Army Medical Center, Washington 25, D.C.
37- 38 Commanding General, QM R&D Comd., QM R&D Cntr., Natick, Mass. ATTN: CBR Liaison Officer
39- 40 Commanding Officer, Chemical Warfare Lab., Army Chemical Center, Md. ATTN: Tech. Library
41 Commanding General, Engineer Research and Dev. Lab., Ft. Belvoir, Va. ATTN: Chief, Tech. Support Branch
42 Director, Waterways Experiment Station, P.O. Box 631, Vicksburg, Miss. ATTN: Library
43 Commanding Officer, Picatinny Arsenal, Dover, N.J. ATTN: ORDBB-TK
44 Commanding Officer, Diamond Ord. Fuze Labs., Washington 25, D.C. ATTN: Chief, Nuclear Vulnerability Br. (230)
45- 46 Commanding General, Aberdeen Proving Grounds, Md. ATTN: Director, Ballistics Research Laboratory
47 Commander, Army Rocket and Guided Missile Agency, Redstone Arsenal, Ala. ATTN: Tech Library
48 Commanding General, White Sands Proving Ground, Las Cruces, N. Mex. ATTN: ORDBS-OM
49 Commander, Army Ballistic Missile Agency, Redstone Arsenal, Ala. ATTN: ORDAB-HT
50 Commanding General, U.S. Army Electronic Proving Ground, Ft. Huachuca, Ariz. ATTN: Tech. Library
51 Commanding General, USA Combat Surveillance Agency, 1124 N. Highland St., Arlington, Va.
52 Director, Operations Research Office, Johns Hopkins University, 6935 Arlington Rd., Bethesda 14, Md.
53 Commanding General, U. S. ORD Special Weapons-Ammunition Command, Dover, N.J.
54 Commander-in-Chief, U.S. Army Europe, APO 403, New York, N.Y. ATTN: Opot. Div., Weapons Br.

NAVY ACTIVITIES

55 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-03EG
56 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-75
57- 58 Chief of Naval Research, D/N, Washington 25, D.C. ATTN: Code 811
59- 60 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
61 Chief, Bureau of Ordnance, D/N, Washington 25, D.C.
62 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 423
63 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
64 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Mrs. Katherine H. Cass
65- 66 Commander, U.S. Naval Ordnance Laboratory, White Oak, Silver Spring 19, Md.
67 Commanding Officer and Director, Navy Electronics Laboratory, San Diego 52, Calif.
68 Commanding Officer, U.S. Naval Mine Defense Lab., Panama City, Fla.
69- 70 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco, Calif. ATTN: Tech. Info. Div.
71- 72 Commanding Officer and Director, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif. ATTN: Code L31
73 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
74 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
75 Officer-in-Charge, U.S. Naval School, CEC Officers, U.S. Naval Construction Bn. Center, Port Hueneme, Calif.
76 Commanding Officer, Nuclear Weapons Training Center, Atlantic, U.S. Naval Base, Norfolk 11, Va. ATTN: Nuclear Warfare Dept.
77 Commanding Officer, Nuclear Weapons Training Center, Pacific, Naval Station, San Diego, Calif.
78 Commanding Officer, U.S. Naval Damage Control Tng. Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course
79 Commanding Officer, Naval Air Material Center, Philadelphia 12, Pa. ATTN: Technical Data Br.
80 Commander, Officer U.S. Naval Air Development Center, Johnsville, Pa. ATTN: NAS, Librarian
81 Commanding Officer, U.S. Naval Medical Research Institute, National Naval Medical Center, Bethesda, Md.
82 Commanding Officer and Director, David W. Taylor Model Basin, Washington 7, D.C. ATTN: Library

[redacted]

83 Commanding Officer and Director, U.S. Naval Engineering Experiment Station, Annapolis, Md.

84 Commander, Norfolk Naval Shipyard, Portsmouth, Va. ATTN: Underwater Explosions Research Division

85 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code AO3H

86 Director, Marine Corps Landing Force, Development Center, MCS, Quantico, Va.

87 Commanding Officer, U.S. Naval CIC School, U.S. Naval Air Station, Glynco, Brunswick, Ga.

88- 90 Chief, Bureau of Naval Weapons, Navy Department, Washington 25, D.C. ATTN: RRLD

AIR FORCE ACTIVITIES

91 Assistant for Atomic Energy, HQ, USAF, Washington 25, D.C. ATTN: DCS/O

92 Hq. USAF, ATTN: Operations Analysis Office, Office, Vice Chief of Staff, Washington 25, D. C.

93- 94 Air Force Intelligence Center, HQ. USAF, ACS/I (AFCIN-3V1) Washington 25, D.C.

95 Director of Research and Development, DCS/D, HQ. USAF, Washington 25, D.C. ATTN: Guidance and Weapons Div.

96 The Surgeon General, HQ. USAF, Washington 25, D.C. ATTN: Bio.-Def. Pre. Med. Division

97 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Doc. Security Branch

98 Commander, Air Defense Command, Ent AFB, Colorado. ATTN: Assistant for Atomic Energy, ADLDC-A

99 Commander, Hq. Air Research and Development Command, Andrews AFB, Washington 25, D.C. ATTN: RDRWA

100 Commander, Air Force Ballistic Missile Div. HQ. ARDC, Air Force Unit Post Office, Los Angeles 45, Calif. ATTN: WDSOT

101-102 Commander, AF Cambridge Research Center, L. G. Hanscom Field, Bedford, Mass. ATTN: CRQST-2

103-105 Commander, Air Force Special Weapons Center, Kirtland AFB, Albuquerque, N. Mex. ATTN: Tech. Info. & Intel. Div.

106-109 Director, Air University Library, Maxwell AFB, Ala.

110 Commander, Lowry Technical Training Center (TW), Lowry AFB, Denver, Colorado.

111 Commandant, School of Aviation Medicine, USAF, Randolph AFB, Tex. ATTN: Research Secretariat

112 Commander, 1009th Sp. Wpns. Squadron, HQ. USAF, Washington 25, D.C.

113-115 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, Ohio. ATTN: WCOSI

116-117 Director, USAF Project RAND, VIA: USAF Liaison Office, The RAND Corp., 1700 Main St., Santa Monica, Calif.

118 Commander, Rome Air Development Ce[illegible], ARDC, Griffi[illegible] AFB, N.Y. ATTN: Documents Library, [illegible]SSL-1

119 Commander, Air Technical Intelligen[illegible] Center, US[illegible], Wright-Patterson AFB, Ohio, ATTN: [illegible]N-4B1a, Libra[illegible]

120 Assistant Chief of Staff, Intellige[illegible], APO 633, New York, N.Y. ATTN: Director [illegible]

121 Commander-in-Chief, Pacific Air Forces, APO [illegible], San Francisco, Calif. ATTN: PFCIE-MB, Base Recovery

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

122 Director of Defense Research and Engineering, Washington 25, D.C. ATTN: Tech. Library

123 Chairman, Armed Services Explosives Safety Board, DOD, Building T-7, Gravelly Point, Washington 25, D.C.

124 Director, Weapons Systems Evaluation Group, Room [illegible], The Pentagon, Washington 25, D.C.

125-128 Chief, Defense Atomic Support Agency, Washington 25, D.C. ATTN: Document Library

129 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex.

130 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex. ATTN: FCTG

131-135 Commander, Field Command, DASA, Sandia Base, Albuquerque, N. Mex. ATTN: FCWT

136 Commander, JTF-7, Arlington Hall Station, Arlington [illegible], Va.

137 Commander-in-Chief, Strategic Air Command, Offutt AFB, Neb. ATTN: OAWS

138 Commander-in-Chief, EUCOM, APO 128, New York, N.Y.

ATOMIC ENERGY COMMISSION ACTIVITIES

139-141 U.S. Atomic Energy Commission, Technical Library, Washington 25, D.C. ATTN: For DMA

142-143 Los Alamos Scientific Laboratory, Report Library, P.O. Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman

144-148 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: H. J. Smyth, Jr.

149-151 University of California Lawrence Radiation Laboratory, P.O. Box 808, Livermore, Calif. ATTN: Clovis G. Craig

152 Essential Operating Records, Division of Information Services for Storage at ERC-E. ATTN: John E. Hans, Chief Headquarters Records and Mail Service Branch, U.S. AEC, Washington 25, D.C.

153 Weapon Data Section, Technical Information Service Extension, Oak Ridge, Tenn.

154-185 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

[redacted]